National Aeronautics and Space Administration

FY 2019 BUDGET ESTIMATES

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FY 2019 PRESIDENT'S BUDGET REQUEST SUMMARY

	Fiscal Year						
	Operating Plan	CR	PBR	Notional			
Budget Authority ($ in millions)	2017	2018	2019	2020	2021	2022	2023
NASA Total	19,653.3	19,519.8	19,892.2	19,592.2	19,592.2	19,592.2	19,592.2
Deep Space Exploration Systems	4,184.0	4,222.6	4,558.8	4,859.1	4,764.5	4,752.5	4,769.8
Exploration Systems Development	3,929.0	--	3,669.8	3,790.5	3,820.2	3,707.5	3,845.6
Advanced Exploration Systems	97.8	--	889.0	1,068.6	944.3	1,045.0	924.1
Exploration Research and Development	157.2	--	--	--	--	--	--
Exploration Research and Technology	826.5	820.8	1,002.7	912.7	912.7	912.7	912.7
LEO and Spaceflight Operations	4,942.5	4,850.1	4,624.6	4,273.7	4,393.3	4,430.3	4,438.0
International Space Station	1,450.9	--	1,462.2	1,453.2	1,471.2	1,466.2	1,451.2
Space Transportation	2,589.0	--	2,108.7	1,829.1	1,858.9	1,829.2	1,807.3
Space and Flight Support (SFS)	902.6	--	903.7	841.4	888.2	934.9	954.6
Commercial LEO Development	--	--	150.0	150.0	175.0	200.0	225.0
Science	5,762.2	5,725.8	5,895.0	5,859.9	5,841.1	5,822.4	5,803.6
Earth Science	1,907.7	--	1,784.2	1,784.2	1,784.2	1,784.2	1,784.2
Planetary Science	1,827.5	--	2,234.7	2,199.6	2,180.8	2,162.1	2,143.3
Astrophysics	1,352.3	--	1,185.4	1,185.4	1,185.4	1,185.4	1,185.4
Heliophysics	674.7	--	690.7	690.7	690.7	690.7	690.7
Aeronautics	656.0	655.5	633.9	608.9	608.9	608.9	608.9
Education	100.0	99.3	--	--	--	--	--
Safety, Security, and Mission Services	2,768.6	2,749.8	2,749.7	2,744.8	2,738.6	2,732.3	2,726.1
Center Management and Operations	1,986.5	--	1,949.6	1,945.4	1,939.8	1,934.1	1,928.5
Agency Management and Operations	782.1	--	800.1	799.4	798.8	798.2	797.6
Construction and Environmental Compliance and Restoration	375.6	358.3	388.2	293.8	293.8	293.8	293.8
Construction of Facilities	305.4	--	305.3	210.9	210.9	210.9	210.9
Environmental Compliance and Restoration	70.2	--	82.9	82.9	82.9	82.9	82.9
Inspector General	37.9	37.6	39.3	39.3	39.3	39.3	39.3
NASA Total	19,653.3	19,519.8	19,892.2	19,592.2	19,592.2	19,592.2	19,592.2

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

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	Fiscal Year						
Budget Authority ($ in millions)	Operating Plan 2017	CR 2018	PBR 2019	Notional 2020	2021	2022	2023
NASA Total	**19,653.3**	**19,519.8**	**19,892.2**	**19,592.2**	**19,592.2**	**19,592.2**	**19,592.2**
Deep Space Exploration Systems	**4,184.0**	**4,222.6**	**4,558.8**	**4,859.1**	**4,764.5**	**4,752.5**	**4,769.8**
Exploration Systems Development	**3,929.0**	**--**	**3,669.8**	**3,790.5**	**3,820.2**	**3,707.5**	**3,845.6**
Orion Program	**1,330.0**	**--**	**1,163.5**	**1,137.7**	**1,134.2**	**1,117.8**	**1,117.8**
Orion Program Integration and Support	**10.5**	**--**	**10.5**	**10.5**	**10.5**	**10.5**	**10.5**
Crew Vehicle Development	**1,319.5**	**1,330.3**	**1,153.0**	**1,127.2**	**1,123.7**	**1,107.3**	**1,107.3**
Space Launch System	**2,127.1**	**--**	**2,078.1**	**2,062.9**	**2,165.1**	**2,131.0**	**2,276.0**
Launch Vehicle Development	**2,072.0**	**2,079.3**	**2,027.2**	**2,001.8**	**2,104.3**	**2,071.4**	**2,216.2**
SLS Program Integration and Support	**55.1**	**--**	**50.9**	**61.2**	**60.9**	**59.6**	**59.8**
Exploration Ground Systems	**471.9**	**--**	**428.2**	**589.9**	**520.8**	**458.7**	**451.9**
EGS Program Integration and Support	**13.4**	**--**	**5.0**	**14.9**	**15.7**	**15.7**	**9.6**
Exploration Ground Systems Development	**458.5**	**426.1**	**423.2**	**575.0**	**505.1**	**443.0**	**442.3**
Advanced Exploration Systems	**97.8**	**--**	**889.0**	**1,068.6**	**944.3**	**1,045.0**	**924.1**
Lunar Orbital Platform - Gateway	**--**	**--**	**504.2**	**662.0**	**540.0**	**558.9**	**459.1**
Advanced Cislunar and Surface Capabilities	**--**	**--**	**116.5**	**146.0**	**163.7**	**300.0**	**320.3**
Exploration Advanced Systems	**97.8**	**--**	**268.2**	**260.7**	**240.6**	**186.1**	**144.7**
Exploration Research and Development	**157.2**	**--**	**--**	**--**	**--**	**--**	**--**
Exploration Research and Technology	**826.5**	**820.8**	**1,002.7**	**912.7**	**912.7**	**912.7**	**912.7**
Early Stage Innovation and Partnerships	**89.7**	**--**	**108.4**	**103.0**	**107.0**	**107.0**	**107.0**
Technology Maturation	**135.0**	**--**	**216.5**	**178.6**	**180.8**	**183.3**	**183.5**
Technology Demonstration	**262.8**	**--**	**332.7**	**293.1**	**286.9**	**284.4**	**284.2**
Laser Comm Relay Demo (LCRD)	**25.7**	**21.5**	**17.2**	**--**	**--**	**--**	**--**
Restore/In-Space Robotic Servicing (ISRS)	**130.0**	**--**	**45.3**	**45.3**	**45.3**	**45.3**	**45.3**
Solar Electric Propulsion (SEP)	**23.4**	**--**	**48.1**	**24.6**	**18.4**	**4.9**	**--**
Small Spacecraft, Flight Opportunities & Other Tech Demonstration	**83.6**	**--**	**222.2**	**223.2**	**223.2**	**234.2**	**238.9**
Human Research Program	**140.0**	**--**	**140.0**	**140.0**	**140.0**	**140.0**	**140.0**

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	Fiscal Year						
	Operating Plan	CR	PBR	Notional			
Budget Authority ($ in millions)	2017	2018	2019	2020	2021	2022	2023
SBIR and STTR	199.0	--	205.0	198.0	198.0	198.0	198.0
LEO and Spaceflight Operations	4,942.5	4,850.1	4,624.6	4,273.7	4,393.3	4,430.3	4,438.0
International Space Station	1,450.9	--	1,462.2	1,453.2	1,471.2	1,466.2	1,451.2
International Space Station Program	1,450.9	--	1,462.2	1,453.2	1,471.2	1,466.2	1,451.2
ISS Systems Operations and Maintenance	1,103.5	--	1,105.5	1,105.5	1,105.6	1,105.6	1,105.6
ISS Research	347.3	--	356.7	347.7	365.6	360.6	345.6
Space Transportation	2,589.0	--	2,108.7	1,829.1	1,858.9	1,829.2	1,807.3
Crew and Cargo Program	1,404.2	--	1,935.6	1,793.2	1,822.6	1,792.8	1,771.0
Commercial Crew Program	1,184.8	--	173.1	35.8	36.3	36.3	36.3
Space and Flight Support (SFS)	902.6	--	903.7	841.4	888.2	934.9	954.6
Space Communications and Navigation	630.1	--	634.1	568.8	615.6	652.9	670.6
Space Communications Networks	546.9	--	523.4	454.8	504.3	549.8	567.4
Space Communications Support	83.2	--	110.8	114.1	111.3	103.1	103.2
Human Space Flight Operations	123.1	--	135.4	136.4	136.4	145.9	147.8
Launch Services	85.7	--	86.6	88.6	88.6	88.6	88.6
Rocket Propulsion Test	43.7	--	47.6	47.6	47.6	47.6	47.6
21st Century Space Launch Complex	20.0	--	--	--	--	--	--
Commercial LEO Development	--	--	150.0	150.0	175.0	200.0	225.0
Science	5,762.2	5,725.8	5,895.0	5,859.9	5,841.1	5,822.4	5,803.6
Earth Science	1,907.7	--	1,784.2	1,784.2	1,784.2	1,784.2	1,784.2
Earth Science Research	462.0	--	451.4	457.4	483.8	507.7	537.8
Earth Science Research and Analysis	332.5	--	305.2	299.2	318.0	321.0	325.0
Computing and Management	129.5	--	146.1	158.2	165.8	186.7	212.8
Earth Systematic Missions	929.7	--	788.1	729.5	689.1	646.5	595.0
Ice, Cloud, and land Elevation Satellite (ICESat-2)	86.5	70.9	23.1	17.6	17.6	17.3	17.3
GRACE Follow-On	33.7	4.7	11.3	12.3	12.2	12.5	12.5
Surface Water and Ocean Topography Mission (SWOT)	61.7	97.9	114.3	85.0	63.9	32.8	11.5
NASA-ISRO Synthetic Aperature Radar (NISAR)	101.4	58.4	131.9	118.6	93.2	89.9	32.4
Landsat 9	198.7	175.8	162.4	114.9	94.2	10.8	2.9
Sentinel-6	54.7	49.2	59.6	64.5	40.4	14.9	35.3

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Budget Authority ($ in millions)	Operating Plan 2017	CR 2018	PBR 2019	Notional 2020	2021	2022	2023
Other Missions and Data Analysis	393.1	--	285.6	316.7	367.7	468.4	483.2
Earth System Science Pathfinder	208.8	--	235.0	273.7	268.2	274.3	287.7
Venture Class Missions	146.6	--	167.5	205.2	199.1	204.0	213.4
Other Missions and Data Analysis	62.3	--	67.5	68.6	69.0	70.3	74.3
Earth Science Multi-Mission Operations	204.9	--	196.9	208.7	225.0	231.6	237.1
Earth Science Technology	62.9	--	59.7	61.6	64.2	67.8	69.6
Applied Sciences	39.4	--	53.1	53.3	53.9	56.3	57.0
Planetary Science	1,827.5	--	2,234.7	2,199.6	2,180.8	2,162.1	2,143.3
Planetary Science Research	230.1	--	258.0	247.6	247.6	247.6	247.6
Planetary Science Research and Analysis	178.1	--	210.3	190.7	190.2	184.1	182.9
Other Missions and Data Analysis	52.0	--	47.7	56.9	57.4	63.5	64.7
Planetary Defense	60.0	--	150.0	150.0	150.0	150.0	150.0
DART	--	--	90.0	71.0	48.0	8.0	2.0
Other Missions and Data Analysis	60.0	--	60.0	79.0	102.0	142.0	148.0
Lunar Discovery and Exploration	19.0	--	218.0	218.0	218.0	218.0	218.0
Other Missions and Data Analysis	19.0	--	218.0	218.0	218.0	218.0	218.0
Discovery	194.6	--	381.2	476.6	375.0	355.6	348.5
InSight	32.3	109.4	22.3	11.8	9.0	9.0	9.0
Lucy	54.5	--	153.3	209.8	154.7	56.4	16.5
Psyche	47.3	--	171.2	214.6	173.3	163.0	40.1
Other Missions and Data Analysis	60.5	--	34.4	40.4	38.0	127.2	282.9
New Frontiers	134.0	--	130.2	163.7	245.0	327.6	388.4
Mars Exploration	647.0	--	601.5	529.7	371.9	290.8	215.3
Mars Rover 2020	408.0	374.3	348.0	296.9	154.8	133.0	60.4
Other Missions and Data Analysis	239.0	--	253.5	232.7	217.1	157.8	154.9
Outer Planets and Ocean Worlds	359.5	--	285.6	213.8	373.3	372.5	375.5
Europa Clipper	275.0	--	264.7	200.2	359.5	358.9	361.0
Other Missions and Data Analysis	84.5	--	20.9	13.6	13.8	13.6	14.5
Technology	183.3	--	210.2	200.2	200.0	200.0	200.0
Astrophysics	1,352.3	--	1,185.4	1,185.4	1,185.4	1,185.4	1,185.4
Astrophysics Research	190.1	--	259.2	280.8	321.5	318.4	310.0
Astrophysics Research and Analysis	73.5	--	83.4	86.6	90.2	92.2	94.2
Balloon Project	34.0	--	39.2	41.7	40.4	40.5	40.6
Science Activation	37.0	--	44.6	44.6	44.6	44.6	44.6

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Other Missions and Data Analysis	45.6	--	92.0	108.0	146.4	141.1	130.7
Cosmic Origins	**779.4**	--	**491.4**	**354.5**	**311.9**	**312.7**	**312.7**
James Webb Space Telescope	569.4	533.7	304.6	197.2	149.8	150.0	150.0
Hubble Space Telescope Operations	97.3	--	78.3	88.3	93.3	98.3	98.3
Stratospheric Observatory for Infrared Astronomy (SOFIA)	85.2	--	74.6	39.8	16.6	--	--
Other Missions and Data Analysis	27.5	--	33.9	29.1	52.2	64.4	64.4
Physics of the Cosmos	**106.2**	--	**136.8**	**139.1**	**113.3**	**108.3**	**105.0**
Exoplanet Exploration	**152.6**	--	**52.4**	**44.5**	**44.6**	**44.4**	**44.9**
Astrophysics Explorer	**124.1**	--	**245.6**	**366.5**	**394.0**	**401.6**	**412.8**
Transiting Exoplanet Survey Satellite (TESS)	74.0	36.9	27.5	3.8	--	--	--
Other Missions and Data Analysis	50.0	--	218.1	362.8	394.0	401.6	412.8
Heliophysics	**674.7**	--	**690.7**	**690.7**	**690.7**	**690.7**	**690.7**
Heliophysics Research	**180.8**	--	**242.7**	**234.3**	**226.7**	**217.9**	**220.6**
Heliophysics Research and Analysis	39.4	--	71.2	66.6	58.6	58.6	58.6
Sounding Rockets	53.3	--	61.1	63.1	68.1	60.1	65.1
Research Range	24.3	--	29.6	27.3	25.6	25.6	25.6
Other Missions and Data Analysis	63.8	--	80.9	77.2	74.4	73.5	71.3
Living with a Star	**368.4**	--	**247.8**	**103.4**	**83.5**	**93.2**	**127.8**
Parker Solar Probe	232.5	241.6	107.2	30.6	22.1	22.2	21.2
Solar Orbiter Collaboration	79.9	59.2	62.3	4.1	4.2	4.2	4.3
Other Missions and Data Analysis	56.0	--	78.2	68.7	57.2	66.7	102.3
Solar Terrestrial Probes	**38.8**	--	**91.0**	**89.9**	**177.7**	**175.6**	**247.9**
Other Missions and Data Analysis	38.8	--	91.0	89.9	177.7	175.6	247.9
Heliophysics Explorer Program	**86.7**	--	**109.2**	**263.1**	**202.9**	**204.1**	**94.4**
Other Missions and Data Analysis	86.7	--	109.2	263.1	202.9	204.1	94.4
Aeronautics	**656.0**	**655.5**	**633.9**	**608.9**	**608.9**	**608.9**	**608.9**
Aeronautics	**656.0**	--	**633.9**	**608.9**	**608.9**	**608.9**	**608.9**
Airspace Operations and Safety Program	**140.6**	--	**90.8**	**96.2**	**120.4**	**122.7**	**122.9**
Advanced Air Vehicles Program	**274.6**	--	**230.6**	**248.5**	**257.1**	**257.8**	**258.3**
Integrated Aviation Systems Program	**125.0**	--	**189.2**	**154.1**	**106.6**	**103.3**	**102.5**

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Budget Authority ($ in millions)	Operating Plan 2017	CR 2018	PBR 2019	Notional 2020	2021	2022	2023
Low Boom Flight Demonstrator	18.5	--	88.3	80.0	45.8	30.0	30.0
Integrated Aviation Systems Program	106.4	--	100.9	74.1	60.8	73.3	72.5
Transformative Aero Concepts Program	115.8	--	123.3	110.1	124.9	125.1	125.1
Education	100.0	99.3	--	--	--	--	--
Safety, Security, and Mission Services	2,768.6	2,749.8	2,749.7	2,744.8	2,738.6	2,732.3	2,726.1
Center Management and Operations	1,986.5	--	1,949.6	1,945.4	1,939.8	1,934.1	1,928.5
Center Institutional Capabilities	1,534.9	--	1,513.6	1,509.4	1,503.8	1,498.1	1,492.5
Center Programmatic Capabilities	451.6	--	436.0	436.0	436.0	436.0	436.0
Agency Management and Operations	782.1	--	800.1	799.4	798.8	798.2	797.6
Agency Management	359.2	--	359.5	358.8	358.2	357.6	357.0
Safety and Mission Success	176.3	--	175.8	175.8	175.8	175.8	175.8
Safety and Mission Assurance	49.6	--	49.5	49.5	49.5	49.5	49.5
Chief Engineer	83.4	--	83.0	83.0	83.0	83.0	83.0
Chief Health and Medical Officer	4.2	--	4.4	4.4	4.4	4.4	4.4
Independent Verification and Validation	39.1	--	38.9	38.9	38.9	38.9	38.9
Agency IT Services (AITS)	219.8	--	238.1	238.1	238.1	238.1	238.1
IT Management	15.9	--	18.3	18.3	18.3	18.3	18.3
Enterprise IT	203.9	--	219.8	219.8	219.8	219.8	219.8
Strategic Capabilities Asset Program	26.8	--	26.7	26.7	26.7	26.7	26.7
Construction and Environmental Compliance and Restoration	375.6	358.3	388.2	293.8	293.8	293.8	293.8
Construction of Facilities	305.4	--	305.3	210.9	210.9	210.9	210.9
Institutional CoF	253.2	--	250.9	210.9	210.9	210.9	210.9
Exploration CoF	8.8	--	25.9	--	--	--	--
Space Operations CoF	36.7	--	18.9	--	--	--	--
Science CoF	2.7	--	9.6	--	--	--	--
Aeronautics CoF	4.0	--	--	--	--	--	--
Environmental Compliance and Restoration	70.2	--	82.9	82.9	82.9	82.9	82.9
Inspector General	37.9	37.6	39.3	39.3	39.3	39.3	39.3
NASA Total	19,653.3	19,519.8	19,892.2	19,592.2	19,592.2	19,592.2	19,592.2

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MESSAGE FROM THE ADMINISTRATOR (ACTING)

As NASA enters its 60th year, it is my privilege to present President Trump's Fiscal Year 2019 budget request of $19.9 billion for NASA.

NASA is renewing its focus on its core exploration mission and the many ways that returns value to the U.S. through knowledge and discoveries, and by strengthening our economy and security, deepening partnerships with other nations, and providing solutions to tough problems and inspiration for the next generation. This budget places NASA once again at the forefront of a global effort to advance humanity's future in space and draws on our Nation's great capacity for innovation and exploration to raise the bar of human potential and improve life across the globe.

The President's request for FY 2019 gives NASA the resources and a clear focus on the exploration and development of the Moon and deep space by leading innovative new commercial and international partnerships to leverage and advance the work we have already been doing in low-Earth orbit (LEO) and in our exploration systems. The budget includes funding for the NASA workforce and facilities necessary to support our future endeavors and charges human exploration, science, and technology efforts to work together as never before to achieve our challenging goals.

Our successful investment with a strong and continually growing U.S. space industry in LEO allows us to focus our energies on farther horizons as private companies continue their successful cargo missions to low-Earth orbit, and move purposefully toward once again launching astronauts from American soil, beginning with test flights this year. This proven strategy is creating jobs and increasing our Nation's security as our industry partners harness their immense innovation and use the energy of a new space economy.

The International Space Station (ISS) is a cornerstone of our integrated approach to deep space. We are dedicated to using the full potential of the station to demonstrate critical technologies, learn about human health in space, and focus commercial energies on the growing LEO economy. We are proposing to end direct Federal funding for the ISS in 2025 and starting this year, we will accelerate the process of transitioning to commercial approaches to ensure a seamless transition to this new operating paradigm as NASA leads a coalition of international and commercial partners to the Moon and then Mars and beyond.

Using the partnership and innovation models we are pioneering in LEO, as well as our exploration systems such as the Space Launch System (SLS) rocket and Orion spacecraft, we will develop new opportunities on and around the Moon.

The SLS and Orion are the critical backbone elements of our future in deep space, and their momentum continues this year toward the first integrated launch of the system in fiscal year 2020 around the Moon and a mission with crew in 2023. In 2019, we'll have an Orion Launch Abort System test to advance critical safety knowledge for the coming missions.

We also will begin to build the in-space infrastructure for long-term exploration and development of the Moon by accelerating our plans to deliver to lunar orbit a power and

MESSAGE FROM THE ADMINISTRATOR (ACTING)

propulsion element as the foundation of a Lunar Orbital Platform-Gateway. This Gateway to the Moon and beyond will give us a strategic presence in cislunar space that will drive our activity with commercial and international partners and help us further explore the Moon and its resources and translate that experience toward human missions to Mars.

Our plan will draw on the interests and capabilities of our industry and international partners as we develop progressively complex robotic missions to the surface of the Moon with scientific and exploration objectives in advance of human return there. In collaboration with our robust scientific activity across the NASA portfolio, these new lunar robotic missions will stretch the capabilities of industry and international partners, while returning science and knowledge we can use for human missions. As NASA leads the way in cislunar space, we will build on and develop partnerships with private industry and other nations to engage the best minds around the world.

These robotic missions of gradually increasing size and scope will advance technology and also support the Lunar Orbiting Platform-Gateway as a place to live, learn, and work around the Moon. The Lunar Orbiting Platform-Gateway will expand what humans can do in the lunar environment and provide opportunities to support those commercial and international missions to the surface that will help us pioneer new technologies such as spaceflight systems, habitation, crew mobility, vehicle and autonomous systems, and robotic precursors for future human missions beyond Earth orbit. All of this work will build infrastructure and knowledge strategically toward humans returning to the Moon and deeper into space.

NASA's incredible science portfolio will continue to increase understanding of our planet and our place in the universe, pursue civilization-level discoveries such as whether or not there is life elsewhere in the universe, and scout for knowledge to inform future human advancement into space. Our robust scientific activity will include lunar surface missions that leverage commercial capabilities; diverse Earth and planetary missions, including continuing Mars robotic missions; and spacecraft to study the Sun and how it influences the very nature of space. Powerful observatories will study other solar systems and their planets and peer back to the dawn of time through other galaxies.

Technology drives exploration, both human and robotic, and helps us solve problems in space and on Earth. It lays the groundwork for our future missions and addresses many needs, including how we'll live in space and how we'll get there, and will support the growing U.S. commercial space industry. We will focus on applications of technology toward deep space exploration and innovative ways to further our goals from concept to testing and flight.

NASA's work has always strengthened our security and the economy, and our ongoing research and testing of new aeronautics technologies is critical in these areas. It will help us lead the world in a global aviation economy with increasing benefits worldwide. Commercial supersonic flight, unmanned aviation systems, advanced hypersonics technologies, and the next generation of aircraft are some of the critical focuses of this important program for our Nation.

MESSAGE FROM THE ADMINISTRATOR (ACTING)

NASA's mission successes will continue to inspire the next generation to pursue science, technology, engineering, and mathematics studies, join us on our journey of discovery, and become the diverse workforce we'll need for tomorrow's critical aerospace careers. We will use every opportunity to engage learners in our work and the many ways it encourages educators, students, and the public to continue making their own discoveries.

This budget funds ongoing operations of NASA Centers and ensures core services are optimized to achieve a safe and healthy workplace. It also strengthens cybersecurity capabilities by safeguarding critical data and systems.

We can't do everything, and as always, we've had to make hard choices, but we will continue to forge new paths and partnerships that strengthen our industrial base and our engagement with other nations to achieve challenging goals that advance our capabilities and increase our security and economic strength. This work will build on our successful history as an exploring Nation and support a dynamic strategy going forward.

NASA will continue to deliver on the promise of U.S. ingenuity and proven leadership in space. This budget moves us toward those goals today.

Robert M. Lightfoot, Jr.
Acting Administrator

BUDGET HIGHLIGHTS

The President's strong support and vision for NASA are reflected in the FY 2019 President's Budget, which will drive new exploration while ensuring that we maintain our continuity of purpose. NASA's historic and enduring purpose is captured in three major strategic thrusts: Discover, Explore, Develop. These correspond to our missions of scientific discovery of our world, of other worlds, and of the cosmos as a whole; missions of exploration in our solar system with humans and robotic probes that expand the frontiers of human experience; and missions that develop and advance new technologies in exploration and aeronautics that allow American industry to increase market share and create new markets on Earth and the near-Earth region of space.

EXTENDING THE HUMAN PRESENCE INTO THE SOLAR SYSTEM

One of NASA's key goals is opening the space frontier with the objective of extending human presence deeper into the solar system starting with returning humans to the Moon through a sustainable human and robotic spaceflight program. The Agency has developed a strategic, pioneering approach to expand the distance and duration of human space exploration, building off the research happening today on the International Space Station. NASA is pushing human presence deeper into space while making new discoveries and strengthening the Nation's diplomatic posture.

The FY 2019 budget request includes $10.5 billion to pursue an exploration campaign that will focus on transitioning LEO operations to commercial providers and returning humans to the Moon and cislunar space, with eventual missions to Mars and beyond. NASA will evolve its core capabilities through continued technical advancements and new approaches and industrial partnerships to maintain the U.S.'s leadership role in human spaceflight. The Agency has developed a phased approach for this activity, starting with ISS and progressing to cislunar space, the lunar surface, then to Mars and beyond. The campaign will be enabled by pursuing near-term milestones for lunar exploration, such as the commercial launch of the power propulsion element, a key element of the Lunar Orbital Platform-Gateway. A new Lunar Discovery and Exploration program would support innovative approaches to achieve human and science exploration goals by funding contracts for commercial transportation services and the development of small rovers and instrument to meet lunar science and exploration needs.

The Exploration Systems Development programs are creating critical components of the architecture for human exploration beyond low-Earth orbit. Orion will take humans to cislunar space atop the Space Launch System (SLS), the heavy-lift rocket that is also supported by Exploration Ground Systems (EGS) for integration and launch. NASA will conduct lunar missions to test systems and concepts, paving the way for long-duration human space exploration. Opening the space frontier requires expansion of technical and scientific knowledge to tackle complex problems and creative new solutions to meet demands never before encountered by humans.

To further enable these goals, the FY 2019 budget realigns the Space Technology Mission Directorate's work to directly support NASA's exploration goals as part of a new Exploration

Research and Technology organization. Exploration Research and Technology rapidly develops, demonstrates, and infuses revolutionary, high-payoff technologies through transparent, collaborative partnerships, expanding the boundaries of NASA's exploration capability. These transformative technologies enable NASA's exploration missions by increasing capabilities to meet human space exploration needs, as well as fostering commercial expansion in low-Earth orbit, cislunar space, and beyond. Technology drives innovation and exploration, as such Exploration Research and Technology supports the following Exploration Campaign's key technology focus areas: Advanced environmental control and life support systems and in-situ resource utilization; Power and propulsion technology; Advanced materials; Communications, Navigation and avionics; Entry, Descent and landing; Autonomous operations; In-space manufacturing and on-orbit assembly; and Research to enable humans to safely and effectively operate in various space environments. NASA's Advanced Exploration Systems (AES) is also developing technologies and maturing systems required for deep-space missions by identifying and pioneering new solutions to technical and human challenges. Exploration Research and Technology also contributes to growing the U.S. industrial and academic base to continue the Nation's economic leadership and strengthen our national security.

The Agency plans to incorporate high-power, solar-electric propulsion technology in its human exploration architecture for deep-space missions. In addition, over the next year, Exploration Research and Technology will conduct several in-space demonstrations, including a deep space atomic clock for advanced navigation and flight testing of a high performing propellant alternative to highly toxic hydrazine. Exploration Research and Technology will complete flight hardware development for the Laser Communications Relay Demonstration and four technologies for the Mars 2020 mission. Through public-private partnerships, Exploration Research and Technology will complete In-Space Robotic Manufacturing and Assembly ground tests to reduce the risk associated with robotic manipulation of structures and remote manufacturing of structural trusses and will initiate a flight demonstration phase. NASA will also continue to restructure its investment in satellite servicing technology to reduce its cost and better position it to support a nascent commercial satellite servicing industry. Additionally, NASA will continue to conduct research on the ISS to understand and mitigate the effects of long-term human exposure to space and the Human Research Program.

In addition, Exploration Research and Technology has developed a diverse portfolio of early-stage research and technology creating a technology pipeline to solve the Agency and Nation's most difficult exploration challenges by partnering with researchers across academia and industry. Exploration Research and Technology will use a combination of unique in-house activities, procurements, NASA Research Announcements, and public-private partnerships to develop and test technologies to enable space exploration missions. Public-private partnerships will enable NASA to share the risk and financial interest with private sector industry to better leverage Government investments. These shared risks and gains include incentivizing technical performance and spurring future commercial markets in the process of developing new capabilities. Technological leadership remains vital to our national security, economic prosperity, and global competitiveness. The Nation's continued economic leadership is, in part, due to the technological investments made in earlier years, through the work of the engineers, scientists, and policy makers who had the wisdom and foresight to make investments our country required to emerge as a global technological leader. That commitment accelerated the economy with the creation of new industries, products, and services that yielded lasting benefits. A technology-driven NASA will continue to fuel our Nation's economic engine for decades to come.

LIVING AND WORKING IN SPACE

NASA capabilities create pathways for discovery and human exploration of space, making discoveries, creating economic and commercial markets and applications, while addressing societal challenges.

These capabilities include research on, or operation of, crew and cargo transportation to the ISS; rocket propulsion testing; safe, reliable, and affordable access to space for NASA science missions and communications satellites, as well as other civil sector missions such as weather satellites for National Oceanic and Atmospheric Administration; and secure, dependable communications with crewed and robotic missions across the solar system and beyond.

ISS is an unparalled global project that exhibits national leadership and engages the pubic and students. It offers a unique platform for NASA and its international partners to learn how to live and work in space. Research, technology demonstrations, tests, and experiments on the ISS continue to advance the capabilities required for future long-duration missions. NASA is making technological advances aboard the ISS in autonomous rendezvous and docking, advanced communications systems, human health and behavior in space, life support systems for habitats, and space suit systems, as well as in basic research in biological and physical sciences. The ISS National Laboratory, managed by the non-profit Center for the Advancement of Science in Space (CASIS), is making great strides in getting new users to the ISS, including private industry and other U.S. Government agencies. These entities are using the ISS for research into pharmaceuticals, biotechnology, and in-space manufacturing, among others, as well as being able to iterate on technology design before moving to operational production.

NASA and the U.S. space transportation industry are well on the way to developing an affordable capability to carry crew to the ISS by the end of 2019, bolstering American leadership while eliminating reliance on the Russian Soyuz to transport American astronauts. This competitive commercial approach, distinct from a traditional NASA-owned and operated system, allows the Agency to reduce costs, improve affordability and sustainability, and stimulate the private sector space industry. With U.S. commercial industry providing cargo resupply services to ISS, NASA is funding development activities for the commercial crew systems. The Agency will purchase commercial crew transportation services using the same model used for cargo services.

Importantly, the FY 2019 budget proposes to end direct U.S. financial support from NASA for the ISS by 2025, and transition to a commercially-operated Low-Earth Orbit (LEO) capability. NASA will continue to bring on new international and commercial partners to ensure a seamless transition to this new operating paradigm for LEO and is providing an additional $150 million in FY19 to support the emergence of new commercial platforms and capabilities.

SCIENCE IS ANSWERING ENDURING QUESTIONS IN, FROM, AND ABOUT SPACE

NASA's Science account funds ongoing discovery and exploration of our planet, other planets and planetary bodies, our star system in its entirety, our galaxy, and the universe beyond. Through the development of space observatories and probes, NASA will continue to inspire the next generation of scientists, engineers, and explorers, provide national leadership in space, and expand human knowledge.

This budget proposes a new Lunar Discovery and Exploration program that partners with industry to go to the Moon and advance science and exploration objectives. It provides full funding for launch in 2018 of the InSight mission to study the deep interior of Mars, the Mars 2020 rover mission, and the recently selected Discovery asteroid missions (Lucy and Psyche). It also supports a Europa Clipper mission launching in 2025 and a new Planetary Defense program that will detect potential asteroid threats to the Earth.

NASA missions continue to enhance our understanding of the Earth. The Sustainable Land Imaging program will provide U.S. users with high-quality, global, land-imaging measurements that are compatible with the existing 45-year Landsat record. This budget supports launch of Landsat 9 as early as FY 2021. The request fully funds Ice, Cloud, and land Elevation Satellite (ICESat-2); Gravity Recovery and Climate Experiment (GRACE-FO); Surface Water and Ocean Topography (SWOT); NASA-ISRO Strategic Aperture Radar (NISAR); and many other future Earth Science missions.

The request fully funds several major missions to advance our understanding of the Sun and its impact on the Earth, including Parker Solar Probe (PSP) and Solar Orbiter Collaboration (SOC). The request also funds the Ionospheric Connection Explorer (ICON) and Global-scale Observations of the Limb and Disk (GOLD) Explorer missions. ICON's goal is to understand the tug-of-war between Earth's atmosphere and the space environment, in the "no man's land" of the ionosphere, while GOLD will measure densities and temperatures in Earth's thermosphere and ionosphere. The request also supports interagency efforts to improve space weather predictive capabilities. In astrophysics, the James Webb Space Telescope, a successor to the Hubble Space Telescope, will launch in the second quarter of 2019.

The budget also supports initiatives that use smaller, less expensive satellites and/or public-private partnerships to advance science. A Science-wide CubeSat/SmallSat initiative is implementing the recommendations from a recent study of the National Academies that concluded that, with ongoing technological progress in both private sector and through Federal investments, these small satellites are on a path to address specific high-priority science goals. A targeted investment strategy focuses technology development on CubeSats/SmallSats in all four SMD science themes to exploit this value and will provide novel partnership opportunities between commercial partners and NASA.

BUDGET HIGHLIGHTS

AERONAUTICS RESEARCH TO ADDRESS AVIATION'S CHALLENGES

The air transportation system of today is a vital part of the U.S. and global economies. It enhances our national security and the industrial base and provides a key catalyst to the Nation's economic development and growth. Aviation is the primary mechanism for connecting major population centers in the U.S. and countries across the world for people and cargo. NASA conducts aeronautics research to bring transformational advances in the safety, capacity, and efficiency of the air transportation system and to enable breakthroughs in the speed and efficiency of transport aircraft that are the backbone of today's aviation system as well as innovative new aircraft concepts and technologies that will enable new aviation markets.

The FY 2019 budget request for NASA Aeronautics supports development of a supersonic X-plane, referred to as the Low Boom Flight Demonstrator (LBFD), scheduled for first flight in FY 2021. The LBFD will demonstrate quiet overland supersonic flight which will enable U.S. industry to open a new market. The request supports cutting edge research to demonstrate and validate new aircraft configurations and propulsion systems. NASA will continue to advance new subsonic aircraft technologies that will dramatically reduce fuel consumption, noise, and emissions. NASA will also continue exploring new hybrid and all-electric propulsion technologies including a flight demonstration of the X-57 Maxwell, a general aviation scale all-electric X-plane.

The request supports a robust investment in air traffic management improvements that will safely increase air traffic capacity and reduce flight delays. In cooperation with the Federal Aviation Administration NASA will conduct a series of flight tests to demonstrate new concepts and technologies that will increase the rate of airport arrivals and departures. NASA Aeronautics will develop and test key technologies that will integrate unmanned aircraft systems (UAS) operations in the National Air Space, as well as realize safe, low-altitude operations of small UAS. The request increases support for hypersonics research which will enhance development of tools and methods to more efficiently design future hypersonic vehicles. With the request, NASA will complete the Advanced Composites project which will deliver a variety of computational tools and guidance that will significantly reduce the time needed to develop and certify new composite structures for aerospace applications.

MANAGING NASA'S PEOPLE AND CAPABILITIES TO SAFELY ACCOMPLISH OUR MISSION

NASA's mission support directly enables NASA's portfolio of missions in space exploration, science, and aeronautics. The Safety, Security, and Mission Services account funds the essential day-to-day technical and business operations required to safely operate and maintain NASA Centers and facilities and the independent technical authority required to reduce risk to life and program objectives for all missions. These mission support activities provide the proper services, tools, and equipment to complete essential tasks, protect and maintain the security and integrity of information and assets, and ensure that personnel work under safe and healthy conditions.

BUDGET HIGHLIGHTS

Planning, operating, and sustaining this infrastructure and our essential services require a number of critical institutional capabilities including management of: human capital; finance; information technology; infrastructure; acquisitions; security; real and personnel property; occupational health and safety; equal employment opportunity and diversity; small business programs; external relations; strategic internal and external communications; stakeholder engagement; and other essential corporate functions. In FY 2019, NASA will strengthen cybersecurity capabilities, safeguarding critical systems and data. NASA will continue to provide strategic and operational planning and management over a wide range of services to help NASA operate in a more efficient and sustainable manner.

The Construction and Environmental Compliance and Restoration account enables NASA to manage the Agency's facilities with a focus on reducing infrastructure, implementing efficiency and high performance upgrades, and prioritizing repairs to achieve the greatest return on investment. In FY 2019, NASA continues to consolidate facilities via institutional construction projects to achieve greater operational efficiency, replacing old, obsolete, costly facilities with fewer, high performance facilities. Programmatic construction of facilities projects provide the specialized technical facilities required by the missions. NASA will decommission and continue preparations to dispose of property and equipment no longer needed for missions. To protect human health and the environment, and to preserve natural resources for future missions, environmental compliance and restoration projects will clean up pollutants released into the environment during past NASA activities.

Pending Congressional action on this budget request, the Office of Education will use the remaining unobligated funds to shutdown the office.

NOTES ON THE BUDGET

NASA'S WORKFORCE

NASA's workforce continues to be its greatest asset for enabling missions in space and on Earth. The civil service staffing levels proposed in the FY 2019 Budget support NASA's scientists, engineers, researchers, managers, technicians, and business operations workforce. It includes civil service personnel at NASA Centers, Headquarters, and NASA-operated facilities. The mix of skills and distribution of workforce across the Agency is, however, necessarily changing.

NASA will continue to explore opportunities across the Agency to find efficiencies in workforce productivity, especially in mission support functional areas. The Agency will apply the valued civil service workforce to priority mission work, adjusting the mix of skills where appropriate. Centers will explore cross-mission opportunities for employees whenever possible, use the range of tools available to reshape the workforce, and continue to identify, recruit, and retain a multi-generational workforce of employees who possess skills critical to the Agency.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

NASA presents the FY 2019 budget request in full-cost, where all project costs are allocated to the project, including labor funding for the Agency's civil service workforce. Note that budget figures in tables may not sum because of rounding.

OUTYEAR FUNDING ASSUMPTIONS

At this time, funding lines beyond FY 2019 should be considered notional.

EXPLANATION OF FY 2017 AND FY 2018 BUDGET COLUMNS

FY 2017 Column

All FY 2017 budget figures reflect funding amounts specified in Public Law 115-31, Consolidated Appropriations Act 2017, as executed under the Agency's FY 2017 Operating Plan. The FY 2017 Actual column in budget tables is consistent with the approved Agency spending plan (i.e., operating plan) control figures at the time of the budget release. Budget structure and figures are adjusted for comparability to the FY 2019 request.

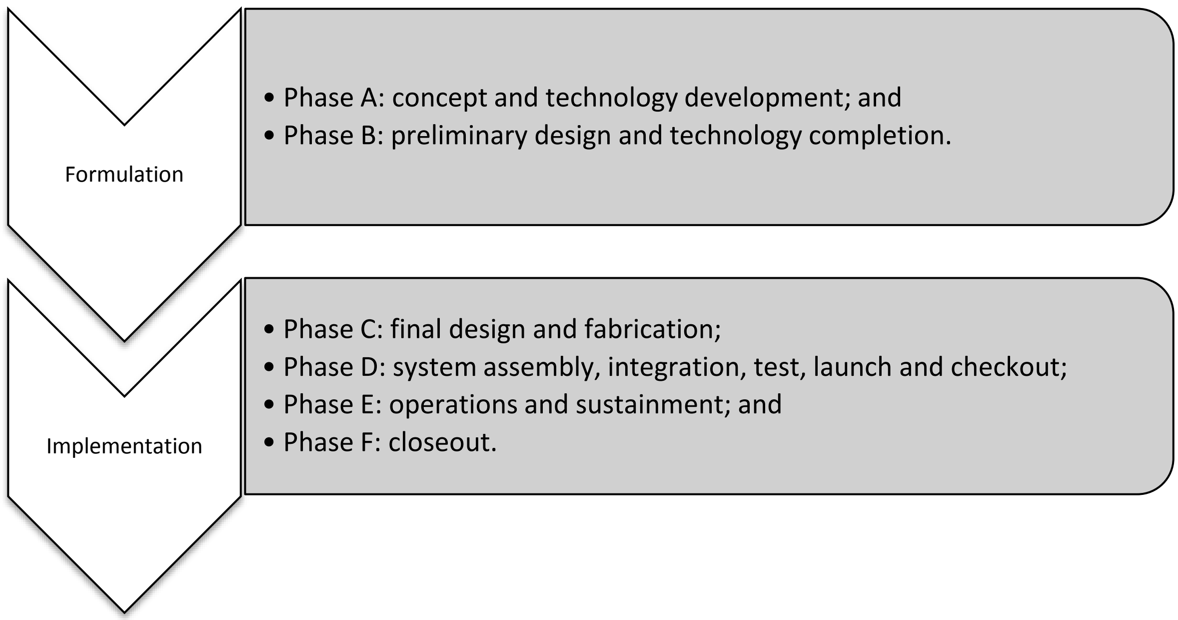
FY 2018 Column

The FY 2018 Enacted column in budget tables displays appropriations enacted in the Continuing Appropriations Act, 2018 (Division D of P.L. 115–56, as amended). The amounts included for FY 2018 reflect the annualized level provided by the continuing resolution. As of budget release, an initial FY 2018 operating plan has not been developed and submitted to the Congress. As a result, budget tables show only account-level appropriations per the continuing resolution. Tables also show tentatively planned FY 2018 funding for projects in development (subject to change pending finalization of the FY 2018 initial operating plan). Budget structures and figures are adjusted for comparability to the FY 2019 budget structure.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

EXPLANATION OF PROJECT SCHEDULE COMMITMENTS AND KEY MILESTONES

Programs and projects follow their appropriate life cycle. The life cycle is divided into phases. Transition from one phase to another requires management approval at Key Decision Points (KDPs). The phases in program and project life cycles include one or more life-cycle reviews, which are considered major milestone events.



A life-cycle review is designed to provide the program or project with an opportunity to ensure that it has completed the work of that phase and an independent assessment of a program or project's technical and programmatic status and health. The final life-cycle review in a given life-cycle phase provides essential information for the KDP that marks the end of that life-cycle phase and transition to the next phase if successfully passed. As such, KDPs serve as gates through which programs and projects must pass to continue.

The KDP decision to authorize a program or project's transition to the next life-cycle phase is based on a number of factors, including technical maturity; continued relevance to Agency strategic goals; adequacy of cost and schedule estimates; associated probabilities of meeting those estimates (confidence levels); continued affordability with respect to the Agency's resources; maturity and the readiness to proceed to the next phase; and remaining program or project risk (safety, cost, schedule, technical, management, and programmatic). At the KDP, the key program or project cost, schedule, and content parameters that govern the remaining life-cycle activities are established.

For reference, a description of schedule commitments and milestones is listed below for projects in Formulation and Implementation. A list of common terms used in mission planning is also included.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Formulation

NASA places significant emphasis on project Formulation to ensure adequate preparation of project concepts and plans and mitigation of high-risk aspects of the project essential to position the project for the highest probability of mission success. During Formulation, the project explores the full range of implementation options, defines an affordable project concept to meet requirements, and develops needed technologies. The activities in these phases include developing the system architecture; completing mission and preliminary system designs; acquisition planning; conducting safety, technical, cost, and schedule risk trades; developing time-phased cost and schedule estimates and documenting the basis of these estimates; and preparing the Project Plan for Implementation.

Formulation Milestone	Explanation
KDP-A	The life-cycle gate at which the decision authority determines the readiness of a program or project to transition into Phase A and authorizes Formulation of the project. Phase A is the first phase of Formulation and means that: • The project addresses a critical NASA need; • The proposed mission concept(s) is feasible; • The associated planning is sufficiently mature to begin activities defined for formulation; and • The mission can likely be achieved as conceived.
System Requirements Review (SRR)	The life-cycle review in which the decision authority evaluates whether the functional and performance requirements defined for the system are responsive to the program's requirements on the project and represent achievable capabilities.
System Definition Review or Mission Definition Review	The life-cycle review in which the decision authority evaluates the credibility and responsiveness of the proposed mission/system architecture to the program requirements and constraints on the project, including available resources, and determines whether the maturity of the project's mission/system definition and associated plans are sufficient to begin the next phase, Phase B.
KDP-B	The life-cycle gate at which the decision authority determines the readiness of a program or project to transition from Phase A to Phase B. Phase B is the second phase of Formulation and means that: • The proposed mission/system architecture is credible and responsive to program requirements and constraints, including resources; • The maturity of the project's mission/system definition and associated plans is sufficient to begin Phase B; and • The mission can likely be achieved within available resources with acceptable risk.
Preliminary Design Review (PDR)	The life-cycle review in which the decision authority evaluates the completeness/consistency of the planning, technical, cost, and schedule baselines developed during Formulation. This review also assesses compliance of the preliminary design with applicable requirements and determines if the project is sufficiently mature to begin Phase C.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Implementation

Implementation occurs when Agency management establishes baseline cost and schedule commitments for projects at KDP-C. The projects maintain the baseline commitment through the end of the mission. Projects are baselined for cost, schedule, and programmatic and technical parameters. Under Implementation, projects are able to execute approved plans development and operations.

Implementation Milestone	Explanation
KDP-C	The life-cycle gate at which the decision authority determines the readiness of a program or project to begin the first stage of development and transition to Phase C and authorizes the Implementation of the project. Phase C is first stage of development and means that: • The project's planning, technical, cost, and schedule baselines developed during Formulation are complete and consistent; • The preliminary design complies with mission requirements; • The project is sufficiently mature to begin Phase C; and • The cost and schedule are adequate to enable mission success with acceptable risk.
Critical Design Review (CDR)	The life-cycle review in which the decision authority evaluates the integrity of the project design and its ability to meet mission requirements with appropriate margins and acceptable risk within defined project constraints, including available resources. This review also determines if the design is appropriately mature to continue with the final design and fabrication phase.
System Integration Review (SIR)	The life-cycle review in which the decision authority evaluates the readiness of the project and associated supporting infrastructure to begin system assembly, integration, and test. The life cycle review also evaluates whether the remaining project development can be completed within available resources, and determine if the project is sufficiently mature to begin Phase D.
KDP-D	The life-cycle gate at which the decision authority determines the readiness of a project to continue in Implementation and transition from Phase C to Phase D. Phase D is a second phase in Implementation; the project continues in development and means that: • The project is still on plan; • The risk is commensurate with the project's payload classification; and • The project is ready for assembly, integration, and test with acceptable risk within its Agency baseline commitment.
Launch Readiness Date (LRD)	The date at which the project and its ground, hardware, and software systems are ready for launch.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Other Common Terms for Mission Planning

Term	Definition
Decision Authority	The individual authorized by the Agency to make important decisions on programs and projects under their authority.
Formulation Authorization Document	The document that authorizes the formulation of a program whose goals will fulfill part of the Agency's Strategic Plan and Mission Directorate strategies. This document establishes the expectations and constraints for activity in the Formulation phase.
Key Decision Point (KDP)	The life-cycle gate at which the decision authority determines the readiness of a program or project to progress to the next phase of the life cycle. The KDP also establishes the content, cost, and schedule commitments for the ensuing phase(s).
Launch Manifest	The list that NASA publishes (the "NASA Flight Planning Board launch manifest") periodically, which includes the expected launch dates for NASA missions. The launch dates in the manifest are the desired launch dates approved by the NASA Flight Planning Board, and are not typically the same as the Agency Baseline Commitment schedule dates. A launch manifest is a dynamic schedule that is affected by real-world operational activities conducted by NASA and multiple other entities. It reflects the results of a complex process that requires the coordination and cooperation by multiple users for the use of launch range and launch contractor assets. Moreover, the launch dates are a mixture of "confirmed" range dates for missions launching within approximately six months, and contractual/planning dates for the missions beyond six months from launch. The NASA Flight Planning Board launch manifest date is typically earlier than the Agency Baseline Commitment schedule date to allow for the operationally driven delays to the launch schedule that may be outside of the project's control.
Operational Readiness Review	The life-cycle review in which the decision authority evaluates the readiness of the project, including its ground systems, personnel, procedures, and user documentation, to operate the flight system and associated ground system(s), in compliance with defined project requirements and constraints during the operations phase.
Mission Readiness Review or Flight Readiness Review (FRR)	The life-cycle review in which the decision authority evaluates the readiness of the project, ground systems, personnel, and procedures for a safe and successful launch and flight/mission.
KDP-E	The life-cycle gate at which the decision authority determines the readiness of a project to continue in Implementation and transition from Phase D to Phase E. Phase E is a third phase in Implementation and means that the project and all supporting systems are ready for safe, successful launch and early operations with acceptable risk.
Decommissioning Review	The life-cycle review in which the decision authority evaluates the readiness of the project to conduct closeout activities. The review includes final delivery of all remaining project deliverables and safe decommissioning of space flight systems and other project assets.
KDP-F	The life-cycle gate at which the decision authority determines the readiness of the project's decommissioning. Passage through this gate means the project has met its program objectives and is ready for safe decommissioning of its assets and closeout of activities. Scientific data analysis may continue after this period.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

For further details, go to:

- NASA Procedural Requirements 7120.5E - NASA Space Flight Program and Project Management Requirements: http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7120&s=5E.
- NASA Procedural Requirements NPR 7123.1B - NASA Systems Engineering Processes and Requirements: http://nodis3.gsfc.nasa.gov/npg_img/N_PR_7123_001B_/N_PR_7123_001B_.pdf.
- NASA Launch Services Web site: http://www.nasa.gov/directorates/heo/launch_services/index.html.

EXPLORATION CAMPAIGN

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2017	FY 2018	FY 2019
Deep Space Exploration Systems	4184.0	4222.6	**4558.8**	4859.1	4764.5	4752.5	4769.8
Exploration Research & Technology	826.5	820.8	**1002.7**	912.7	912.7	912.7	912.7
LEO & Spaceflight Operations	4942.5	4850.1	**4624.6**	4273.7	4393.3	4430.3	4438.0
Exploration Campaign COF	45.5	22.4	**44.8**	--	--	--	--
Elements of Science	39.0	36.0	**268.0**	268.0	268.0	268.0	268.0
Total Exploration Campaign	**10037.5**	**9951.9**	**10498.9**	**10313.5**	**10338.5**	**10363.5**	**10388.5**
Change from FY 2018			**547.0**				
Percentage change from FY 2018			**5.5%**				

Following the initial meeting of the National Space Council in October 2017, President Trump signs *Space Policy Directive One*, charging NASA to develop an innovative and sustainable program of exploration. NASA will return humans to the Moon for the first time in nearly 50 years for long-term exploration and utilization, followed by robotic & human missions to Mars.

NASA will lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system, and to bring new knowledge and opportunities back to Earth. Beginning with missions beyond low Earth orbit (LEO), the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations.

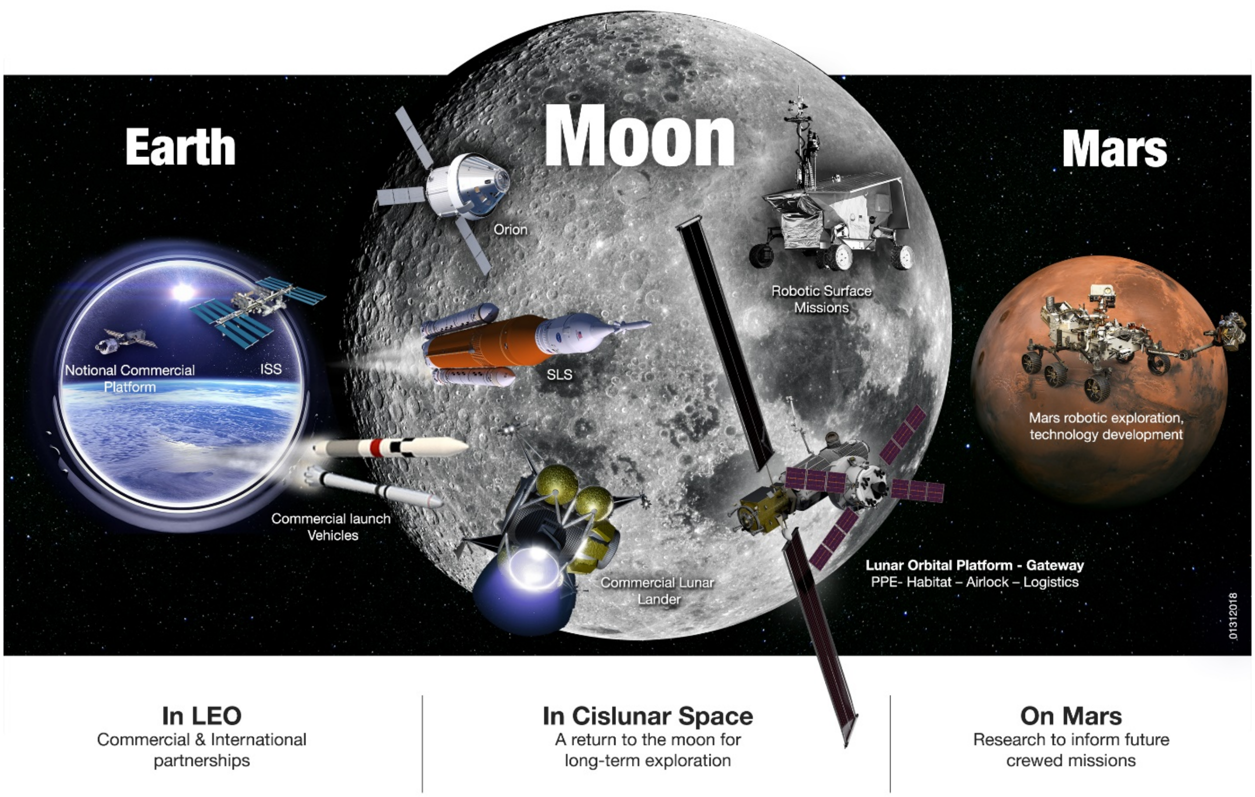
Building on the Space Launch System, Orion, and emerging commercial capabilities, this Budget expands exploration by 1) initiating planning to transition low earth orbit operations to viable and stable industry partners and 2) pursuing a cis-lunar strategy that establishes U.S. preeminence to, around, and on the Moon. NASA will engage with partners through non-traditional partnerships, commercial service purchases, and expanded international cooperative agreements. In order to implement this ambitious program of exploration, NASA's FY2019 budget prioritizes human exploration and related activities.

With the funding requested in the FY 2019 budget, NASA will:

- increase utilization of the International Space Station (ISS), taking full advantage of a fourth U.S. Operating Segment crew member;
- partner with industry to establish a greater commercial presence in low Earth orbit in support of a transition to NASA use of commercial capabilities – potentially including sustainable use of elements of the ISS – by 2025;
- implement a U.S.-led strategy utilizing industry and international partner capabilities to enable human exploration of the lunar surface;

- complete development activities for an uncrewed test flight of the integrated Space Launch System & Orion Crew Vehicle, strengthening American capabilities to launch astronauts, cargo, and spacecraft with a crewed flight by 2023;
- initiate a series of industry and government led robotic lunar missions as early as 2019, establishing a continual human presence on and around the lunar surface;
- launch the first element of a Lunar Orbital Platform-Gateway in 2022, establishing the initial exploration infrastructure orbiting the Moon;
- focus investments in research and technologies applicable to deep-space exploration opportunities with industry and international partners; and

Through these activities, NASA's budget will realize exploration opportunities in the near-term and set the stage for America space leadership decades to come.



EXPLORATION CAMPAIGN

Exploration at NASA will continue to be a cross-functional effort at Headquarters and across the Centers. The FY19 budget structure aligns Exploration Campaign work under four major accounts.

LEO & Spaceflight Operations

Centralizing space access in a Low Earth Orbit (LEO) and Spaceflight Operations account enables NASA to better plan for both government and commercial access to space, and lays the foundation to support future commercial operations in LEO. These activities support existing and future space operations, commercialization, and space and flight support capabilities for all NASA and non-NASA missions.

NASA's industry partners have proven themselves capable of successfully launching and returning cargo to and from Earth, and NASA is building upon that partnership with commercial crew launches to and from the ISS beginning in 2019.

NASA will continue its existing operations and further expand partnerships on the ISS. Direct federal support for ISS will end in 2025, though industry could potentially continue to operate certain elements or capabilities. NASA will expand international and commercial partnerships over the next seven years in order to ensure continued human access to and presence in low Earth orbit. NASA will encourage the emergence of an environment in LEO where NASA is one of many customers of a non-governmental human space flight enterprise. A new Commercial LEO Development effort, initially funded with $150 million in FY 2019, will provide the resources needed for NASA to assist industry in the near term to develop a commercial low Earth orbit presence, with and without crews.

Deep Space Exploration Systems

NASA will establish a Lunar Orbital Platform-Gateway in cislunar space, to include a power and propulsion element by 2022, and habitation, airlock, and the required logistics capabilities soon after. NASA will use this infrastructure as part of a broader strategy to explore and utilize the Moon and its surface.

As part of this strategy to accelerate exploration, NASA will utilize a multitude of launch capabilities. Additionally, the first un-crewed test flight of the SLS/Orion system will occur in mid-2020, leading to crewed missions in 2023. SLS and Orion will allow crewed exploration further into space than ever before.

In parallel, NASA is planning to develop a series of robotic lunar missions to the surface of the Moon. NASA will use innovative acquisition approaches to engage U.S. industry capabilities as the agency moves toward human exploration of the lunar surface. NASA will also work with international partners in this endeavor.

Exploration Research & Technology

Research & development of new technologies and capabilities lays the groundwork that enhances and enables deep space exploration. Exploration Research and Technology will consolidate the technology development program content previously funded by Space Technology Mission Directorate and Advanced Exploration Systems, integrating and refocusing these activities toward Space Exploration. This will enable NASA's workforce, in concert with industry and academia, to focus on innovative ways to further humankind's exploration from conception to testing to spaceflight.

The Human Research Program (HRP) will continue to conduct cutting edge research on the effect of spaceflight and the space environment on the human body, including experiments on the ISS and other acceptable private low-Earth orbit platforms in microgravity. HRP will support the development of Deep Space Exploration habitat concepts to ensure crew health and performance risks are adequately addressed.

Scientific Exploration

The final element of exploration comes from NASA's Science Mission Directorate (SMD), which will see no organizational changes – but will refocus its efforts around exploration and scientific discovery.

SMD will partner with industry to send robotic lunar missions to further explore and utilize the surface of the Moon. SMD will also continue to study and explore Mars. As it prepares for a potential sample return mission, it will explore technologies that will inform future crewed missions and launches.

Restructure

NASA will restructure the Agency to align with our focus on accelerating human exploration beyond low-Earth orbit. There are two options currently under review:

1) Creation of two new exploration-focused mission directorates, eliminating the current HEO and STMD structure –
    a. An Exploration Operations Mission Directorate that will focus ISS, LEO operations, and cross cutting support areas required to support exploration such as communications, and propulsion testing, etc.
    b. An Exploration Systems and Technology Mission Directorate that will focus on deep space mission elements and technology developments needed for sustainable human exploration.
2) Creation of a single exploration-focused mission directorate, consolidating all the exploration-focused content in the current HEOMD and STMD organization.

NASA will assess these two options (and any hybrid options that may arise), and prepare for implementation at the start of the FY 2019 budget year.

As NASA works through the details of implementing these changes, we expect further refinement to the ideas, budgets, and specifics of these exploration proposals, and NASA will keep the Congress apprised of its work.

Taken together, NASA's FY 2019 budget proposal lays out an aggressive exploration program of work for NASA, and includes $10.5 billion in funding to achieve those objectives. This funding will empower American global leadership, spur innovation and economic growth, and return the United States to the forefront of space exploration.

DEEP SPACE EXPLORATION SYSTEMS

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Exploration Systems Development	3929.0	--	**3669.8**	3790.5	3820.2	3707.5	3845.6
Advanced Exploration Systems	97.8	--	**889.0**	1068.6	944.3	1045.0	924.1
Exploration Research and Development	157.2	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**4184.0**	**4222.6**	**4558.8**	**4859.1**	**4764.5**	**4752.5**	**4769.8**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

In prior years, Exploration R&D included both AES and Exploration R&D. Amounts shown in the Exploration R&D line reflect funding that is now reflected in the Exploration Research and Technology account as well as the Advanced Exploration Systems account.

DEEP SPACE EXPLORATION SYSTEMS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	FY 2020	Notional FY 2021	FY 2022	FY 2023
Exploration Systems Development	3929.0	--	**3669.8**	3790.5	3820.2	3707.5	3845.6
Advanced Exploration Systems	97.8	--	**889.0**	1068.6	944.3	1045.0	924.1
Exploration Research and Development	157.2	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**4184.0**	**4222.6**	**4558.8**	**4859.1**	**4764.5**	**4752.5**	**4769.8**
Change from FY 2018			**336.2**				
Percentage change from FY 2018			**8.0%**				

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

In prior years, Exploration R&D included both AES and Exploration R&D. Amounts shown in the Exploration R&D line reflect funding that is now reflected in the Exploration Research and Technology account as well as the Advanced Exploration Systems account.

NASA has been charged with leading an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system, starting with a return to the Moon. The Agency has developed an approach to incrementally expand the distance and duration of human space exploration by building upon the work happening today on the International Space Station. Beginning with new missions beyond low Earth orbit (LEO), the U.S. will lead a return of humans to the Moon and lunar surface for long-term exploration and utilization, followed by human missions to Mars and other destinations.

The FY 2019 President's Budget includes a new account structure for human space exploration and technology program to improve alignment of funding with NASA's new strategic space exploration objectives. It renames the Space Operations, Exploration, and Space Technology accounts as LEO and Spaceflight Operations, Deep Space Exploration Systems, and Exploration Research and Technology, and realigns some program funding. As part of this realignment, NASA also plans to restructure the Human Exploration and Operations Mission Directorate (HEOMD) and Space Technology Mission Directorate.

The Deep Space Exploration Systems account consists of two programs, Exploration Systems Development (ESD) and Advanced Exploration Systems (AES), which provide for the development of systems and capabilities needed for human exploration of space.

The ESD programs include the Orion crew capsule, the Space Launch System (SLS) rocket, and the Exploration Ground Systems (EGS) that support integration and launch. This space transportation system is a key component of NASA's strategy for exploration in cislunar space and will have a first un-crewed test flight in FY 2020 and a first crewed test flight in 2023.

The AES division focuses on integrating and testing technologies needed for living and working in cislunar space and for future human deep space exploration, and pursues these goals using a combination of unique in-house activities and public-private partnerships. In the FY 2019 President's Budget, NASA proposes three major initiatives: (1) to establish a Lunar Orbital Platform-Gateway (LOP-G) in cislunar space, to include a power and propulsion element (PPE) by 2022, and habitation, airlock, and the required logistics elements thereafter; (2) a new campaign in Advanced Cislunar and Surface Capabilities (ACSC) that will focus on engaging non-traditional U.S. industry partners and sectors in the space program and using innovative approaches to combine lunar robotics, a cislunar presence, and lunar landing capabilities, involving commercial and international participation; and (3) investment in Exploration Advanced Systems, which includes next generation habitation capabilities, and ground test habitation prototypes developed by private-public partnership to evaluate human factors for different habitat configurations, assess how the various systems interact together and with other capabilities like propulsion modules and airlocks, and provide platforms to test and ensure that the standards and common interfaces being considered are well designed. AES will have close collaboration and partnering between HEOMD, Space Science Mission Directorate, and other programs.

All of these efforts are focused on the Exploration Campaign supporting human exploration of deep space.

For more programmatic information, go to: http://www.nasa.gov/directorates/heo/home/index.html.

EXPLORATION SYSTEMS DEVELOPMENT

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Orion Program	1330.0	-	**1163.5**	1137.7	1134.2	1117.8	1117.8
Crew Vehicle Development	1319.5	1330.3	**1153.0**	1127.2	1123.7	1107.3	1107.3
Orion Program Integration and Support	10.5	-	**10.5**	10.5	10.5	10.5	10.5
Space Launch System	2127.1	-	**2078.1**	2062.9	2165.1	2131.0	2276.0
Launch Vehicle Development	2072.0	2079.3	**2027.2**	2001.8	2104.3	2071.4	2216.2
SLS Program Integration and Support	55.1	-	**50.9**	61.2	60.9	59.6	59.8
Exploration Ground Systems	471.9	-	**428.4**	589.9	520.8	458.7	451.9
Exploration Ground Systems Development	458.5	426.1	**423.2**	575.0	505.1	443.0	442.3
EGS Program Integration and Support	13.4	-	**5.2**	14.9	15.7	15.7	9.6
Construction & Envrmtl Compl Restoration	8.8	5.8	**25.9**	0.0	0.0	0.0	0.0
Exploration CoF	8.8	5.8	**25.9**	0.0	0.0	0.0	0.0
Total Budget	**3937.8**	**3908.1**	**3695.9**	**3790.5**	**3820.1**	**3707.5**	**3762.3**
Change from FY 2018			**-212.2**				
Percentage change from FY 2018			**-5.43%**				

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

Total budget in FY 2017-2019 exceeds appropriated amount because it is a combination of the Exploration portion of the CECR account and the ESD account.

EXPLORATION SYSTEMS DEVELOPMENT

A view of the Mobile Launcher under construction at NASA's Kennedy Space Center in Florida in January 2018.

NASA's Exploration Systems Development programs are working together to build the space transportation system made up of the Orion crew vehicle, Space Launch System (SLS) rocket, and the Exploration Ground Systems. This system will enable the Agency's bold new missions to extend human presence into the solar system, starting with a return to the Moon.

NASA's Orion spacecraft is designed to support human exploration missions to deep space with a crew of four for periods of 21 days. Building upon more than 50 years of spaceflight research and development, Orion is designed to meet the evolving needs of our nation's deep space exploration program for decades to come. Its versatile design will be able to carry crew to space, provide emergency abort capability, sustain crew during space travel, and provide safe reentry at deep-space-return velocities. With modifications and the addition of new modules, most of the Orion capsule systems could be capable of operations in deep space for periods of time up to 1,000 days. The Orion systems are designed to operate in a contingency mode to augment life support systems in other space transport systems.

The SLS rocket is a heavy-lift launch vehicle for a new era of exploration beyond Earth's orbit into deep space. SLS will launch astronauts in the Orion spacecraft on missions to cislunar space and other destinations. With the highest-ever payload mass and volume capability and energy to speed missions through space, SLS is designed to be flexible and evolvable, to meet a variety of crew and cargo mission needs.

The objective of exploration ground systems is to prepare KSC to process and launch next-generation vehicles and spacecraft. To achieve this transformation, NASA is developing new ground systems while refurbishing and upgrading infrastructure and facilities to meet tomorrow's demands. This modernization effort keeps maximum flexibility in order to accommodate a multitude of government, commercial and other customers. Drawing on five decades of excellence in processing and launch, NASA is paving the way to the spaceport's future. KSC is now the multi-user spaceport that was envisioned post Shuttle retirement.

As NASA works towards building a sustainable exploration program, the agency is focused on looking at ways to reduce production and operations costs. Through reduction in costs, the Agency can focus on capabilities needed for future deep space systems and successful exploration missions.

ORION PROGRAM

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Crew Vehicle Development	1319.5	1330.3	**1153.0**	1127.2	1123.7	1107.3	1107.3
Orion Program Integration and Support	10.5	--	**10.5**	10.5	10.5	10.5	10.5
Total Budget	**1333.0**	**--**	**1163.5**	**1137.7**	**1134.2**	**1117.8**	**1117.8**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

FY 2018 reflects funding amounts enacted in Public Law 115-31, Consolidated Appropriations Act, 2017, reduced by .6791% as specified in Division D of the Continuing Appropriations Act, 2018, P.L. 115-56.

The Orion Program is continuing to take major steps toward transporting humans safely to deep space and back. Orion will serve as an exploration vehicle that will carry crew to space, provide emergency abort capability, sustain crew during space travel, and provide safe re-entry from deep space return velocities. This capsule-shaped vehicle has a familiar look, but it incorporates numerous technology advancements and innovations. The spacecraft will enable extended duration missions beyond Earth orbit and into deep space.

Orion design, development, and testing (including the flight tests) will have the spacecraft ready to carry crew no later than FY 2023. Future flights of the Space Launch System (SLS) and the Orion spacecraft into cislunar space will extend our capability for human deep space exploration operations, reducing the overall risk as mission durations extend.

For further programmatic information, go to: http://www.nasa.gov/orion.

Program Elements

ORION PROGRAM INTEGRATION AND SUPPORT

Orion program integration and support activities manage the SLS and Exploration Ground System (EGS) program interfaces. This effort is critical to ensuring Orion's performance meets technical and safety specifications, and supports programmatic assessments key to achieving integrated technical, cost, and schedule management. In addition, the Orion integration effort is vital to managing interfaces with other HEOMD activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across the three programs enables the Agency to avoid potential design overlaps, schedule disconnects, and cost issues.

CREW VEHICLE DEVELOPMENT

See the Crew Vehicle Development section.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023	BTC	Total
Formulation	4666.7	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	4666.7
Development/Implementation	1534.4	1281.6	1321.4	**1160.1**	821.7	306.5	126.6	20.0	0.0	6572.3
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2018 MPAR LCC Estimate	**6201.1**	**1281.6**	**1321.4**	**1160.1**	**821.7**	**306.5**	**126.6**	**20.0**	**0.0**	**11239.0**
Total Budget	**6210.9**	**1319.5**	**1330.3**	**1153.0**	**1127.2**	**1123.7**	**1107.3**	**1107.3**	**0.0**	**14479.2**
Change from FY 2018				**-177.3**						
Percentage change from FY 2018				**-13.3%**						

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

The difference between the total budget and the MPAR LCC estimate is the total budget includes content outside of EM-2 and excludes CoF; LCC only includes EM-2 content, including CoF.

The total budget prior line represents FY 2011 pre-formulation and FY 2012 - FY2016 budgets, excluding CoF and additional expenditures from 2005-2011 under the Constellation program.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

October 23, 2017 Orion heat shield for EM-1 moves toward the thermal chamber in Neil Armstrong Operations and Checkout building at NASA's KSC in Florida. It will undergo a thermal cycle test to verify acceptable workmanship and material quality.

PROJECT PURPOSE

Orion will be capable of transporting humans to the Moon and into deep space, sustaining them longer than ever before, and returning them safely to Earth. Drawing from more than 50 years of human spaceflight Research and Development (R&D) and stimulating new and innovative manufacturing and production capabilities, Orion's design will meet the evolving needs of our Nation's space program. For further programmatic information, go to http://www.nasa.gov/orion.

EXPLANATION OF MAJOR CHANGES IN FY 2019

After completing a comprehensive review of the launch schedule, NASA has established an EM-1 integrated launch date of no earlier than December 2019. This date represents a time frame where it is anticipated that a majority of the hardware will be ready to support final launch integration and flight activities. While the review of the possible manufacturing and production schedule indicate a launch date of June 2020, the Agency is managing to December 2019. Mitigation strategies to protect the December 2019 date are principally focused on critical path areas related to the Space Launch System (SLS) core stage production and European Space Agency service module delivery.

NASA will test the Orion's launch abort system, known as Ascent-Abort 2, ahead of the EM-1 launch. The test is targeted for April 2019 and will evaluate the launch abort system's ability to get crew to safety if needed during ascent.

PROJECT PARAMETERS

Orion will be able to carry a crew of four astronauts to cis-lunar space and beyond, and provide habitation and life support for up to 21 days. The spacecraft's three components are the Crew Module, European Service Module (ESM), and Launch Abort System (LAS), with a separate adapter to connect the spacecraft and launch vehicles. Although the module has a familiar visual shape, its interior and exterior capabilities far exceed any geometrically similar predecessors. The state of the art crew systems will provide a safe environment within which to live and work for long durations far from Earth. Orion's advanced heat shield will protect the crew from reentry heating during a high-speed return from the lunar vicinity – heating that will exceed that experienced by any human spacecraft in over four decades. The service module comprises a crew module adapter and the ESA-designed and developed service module. Together they provide in-space power, propulsion, and other life support systems. On a tower atop the crew module sits the LAS, which in the event of an emergency during launch or climb to orbit, will

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

activate within milliseconds to propel the crew module away from the launch vehicle to safety. The abort system also provides a protective shell that shields the crew module from dangerous atmospheric loads and heating during ascent. Once Orion is out of the atmosphere and safely on its way to orbit, the spacecraft will jettison the LAS.

ACHIEVEMENTS IN FY 2017

The vast majority of program content is on track for EM-1, and work is rapidly being transitioned to future flights and planned upgrades. As previously discussed, the program has experienced delays and issues that required a replan of program schedules for EM-1. Some of the most critical issues include the integrated manufacturing, test, and processing schedules based on projection of the ESM delivery. Early production issues are not unprecedented for an activity of this scope and ambition.

The Orion Program completed and shipped the ESM Structural Test Article inside NASA's Super Guppy aircraft from NASA's KSC in Florida to a Lockheed Martin facility near Denver in April 2017 where it is part of the integrated CSM structural test program. This structure is a full-scale replica of the EM-1 Orion spacecraft, and this series of tests will ensure the space-bound article is ready to withstand the pressure and loads it will endure during launch, flight and landing.

At Promontory, Utah, engineers successfully tested the abort motor for Orion's launch abort system firing the 17-foot-tall motor for its full five-second burn. The motor was fastened to a vertical test stand with its nozzles pointed toward the sky for the qualification test. It produced enough thrust to lift 66 large SUVs off the ground. The launch abort system is positioned on top of the Orion Crew Module and is designed to activate within milliseconds to protect astronauts if a problem arises during launch and ascent by pulling the spacecraft away from a failing rocket, and positioning it for a safe landing.

Orion's ESM Propulsion Qualification Module (PQM) was successfully installed at NASA's White Sands Test Facility, New Mexico in February 2017. The all-steel PQM structure is used to test the propulsion system on Orion, including hot firing of the Orbital Maneuvering System (OMS), engine and thrusters. Orion completed hot-fire acceptance testing of eight auxiliary engines that will be used on the first flight of Orion spacecraft with the SLS rocket. The auxiliary engines, which will be located in four pairs on the outside of the ESM, work in concert with the main OMS engine to propel the Orion spacecraft to and from the deep space destinations.

In July 2017, NASA and Department of Defense team tested Orion exit procedures in a variety of scenarios in the waters off the coast of Galveston, Texas. These tests provide valuable information on recovery team procedure and hardware, as they ensure that future Orion astronauts will be safely recovered after splashdown off of the California coast upon completion of their missions.

The Program conducted several successful Orion parachute tests at the U.S. Army Proving Ground in Yuma to qualify the Orion capsule for human flight. In the most recent test, the capsule was dropped out of a C-17 aircraft at more than 4.7 miles in altitude and free fell for 20 seconds, which was required to provide a maximum dynamic pressure test condition for the parachutes.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Engineers at the Space Power Facility at GRC's Plum Brook station in Sandusky, Ohio successfully conducted acoustic testing on the ogive panels. The ogive panels protect Orion's crew module from harsh aerodynamic and acoustic conditions which occur during launch or in case of an abort.

Production of the EM-1 Crew Module and Crew Module Adapter (CMA) at the KSC Neil Armstrong Operations and Checkout Center has made significant progress. Both the Crew Module and CMA successfully completed initial power on tests where engineers and technicians connected the vehicle management computers to Orion’s power and data units to ensure the systems communicated precisely with one another to accurately route power and functional commands throughout the spacecraft for the duration of a deep space exploration mission.

A key step of the heat shield assembling process, Avcoat blocks have been fitted around the Orion EM-1 Crew Module heat shield inside the Neil Armstrong Operations and Checkout Building high bay at KSC. The heat shield protects the spacecraft and the astronauts inside from searing temperatures experienced during re-entry through Earth's atmosphere on the return home from the vicinity of the Moon.

In addition, the Orion Program began manufacturing of components for the EM-2 mission, including the crew module forward and aft bulkheads, the crew module cone panel, solar cells, and EM-2 motors.

WORK IN PROGRESS IN FY 2018

In support of EM-1, the Orion Program will complete testing of the flight software functions, such as: ascent aborts, safe mode, fault detection, isolation and recovery, optical navigation, maneuver plan management, and propulsion failure detection. These tests are essential for identifying software problems and validating proper functionality and performance of the spacecraft.

Orion will complete production of the EM-1 CMA. Orion will install the heat shield on the Crew Module and take delivery of the ESM at KSC in FY 2018 and mated the ESM to the CMA to complete the Service Module assembly. The completed Service Module will be subsequently joined to the Crew Module, resulting in the combined Crew and Service Module.

In parallel to EM-1 launch preparation, Orion will continue building the spacecraft for the first crewed mission, EM-2. FY 2018 funding also supports missions beyond EM-2. Orion will complete Crew Module primary structure welding and deliver it to KSC; start CMA assembly and integration; and start LAS fabrication and assembly.

Orion will complete assembly of the AA-2 Crew Module and Separation Ring in preparation for the FY 2019 launch of the AA-2 test flight.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

Orion will ship the integrated EM-1 Crew Module and Service Module to Plum Brook Station for thermal vacuum, acoustics, and electromagnetic interference testing. Once that is completed, the mated Crew Module/Service Module will be returned to KSC for final launch processing. Orion will begin stacking and integrating the CSM in the LAS Facility and mate the LAS to Orion Crew and Service Module. After

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

the mating, it will be delivered to Ground Operations at KSC for final preparation and stacking in the Vehicle Assembly Building.

Orion will release the EM-1 final software and complete the test campaign that will verify and validate the software for use during the EM-1 mission.

Orion will complete the structural test campaign in Denver and ship the test article to LaRC for subsequent water impact testing.

Orion will deliver the AA-2 test article to KSC and complete the final assembly and stacking operations in support of the test flight in FY2019, which will demonstrate the ability to safety separate the Crew Module from the SLS during an ascent abort scenario.

Orion will complete Crew Module secondary structure and component assembly for EM-2 and will complete heatshield to lower backshell pre-fit, and start Crew Module Clean Room Operations for propulsion and Environment Control and Life Support System (ECLSS) welding.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2019 PB Request
System Design Review (SDR)		Aug 2007
PDR		Aug 2009
Key Decision Point (KDP)-A	Feb 2012	Feb 2012
Resynchronization Review		Jul 2012
KDP-B	Q1 FY 2013	Jan 2013
Delta PDR	Q4 FY 2013	Aug 2014
EFT-1 Launch	Dec 2014	Dec 2014
KDP-C, Project Confirmation	FY 2015	Sep 2015
CDR	Oct 2015	Oct 2015
Abort Ascent (AA)-2 Flight Test	FY 2020	FY 2019
EM-1 Launch Readiness	FY 2018	FY 2020
EM-2 Launch Readiness*	FY 2023	FY 2023

** The program is currently reviewing cost and schedule impacts based on the change to the EM-1 launch readiness date.*

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2015	6,768.4	70	2018	6,616.6	-2.2	EM-2	Apr 2023	Apr 2023	0

The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

The Current Year Development Cost Estimate and Milestone data reflects the planning for the EM-2 mission based on the Agency Baseline Commitment (ABC) established for the program in September 2015. The program is currently reviewing cost and schedule impacts based on the change to the EM-1 launch readiness date. The cost change amount reflects a transfer of funding to formulation costs and does not represent a reduction in the lifecycle cost estimates.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**6,768.4**	**6,616.6**	**-151.8**
Mission Operations	281.6	273.3	-8.3
Program Management	671.5	634.4	-37.1
Safety and Mission Assurance	191.4	182.4	-9.0
Spacecraft	3,205.1	3,200.5	-4.6
Systems Engineering and Integration	539.3	501.7	-37.6
Test and Verification	460.6	426.9	-33.7
Other Direct Project Costs	1,418.9	1,397.4	-21.5

The Current Year Development Cost Estimate and Milestone data reflects the planning for the EM-2 mission based on the Agency Baseline Commitment (ABC) established for the program in September 2015. The program is currently reviewing cost and schedule impacts based on the change to the EM-1 launch readiness date. The cost change amount reflects a transfer of funding to formulation costs and does not represent a reduction in the lifecycle cost estimates.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Crew Module	The transportation capsule provides a safe habitat for the crew as well as storage for consumables and research instruments, and serves as the docking port for crew transfers.	Provider: JSC Lead Center: JSC Performing Center(s): Ames Research Center (ARC), GRC, JSC, and Langley Research Center (LaRC) Cost Share Partner(s): N/A	None
Service Module	The service module supports the crew module from launch through separation before reentry.	Provider: ESA Lead Center: GRC Performing Center(s): ARC, GRC, JSC, and LaRC Cost Share Partner(s): ESA	None
Launch Abort System	The LAS maneuvers the crew module to safety in the event of an emergency during launch or climb to orbit.	Provider: JSC Lead Center: LaRC Performing Center(s): JSC, LaRC, and Marshall Space Flight Center (MSFC) Cost Share Partner(s): N/A	None

Project Risks

Risk Statement	Mitigation
If: ESM delivery schedule delays Then: There is a possibility that the integration of the ESM and Crew Module will be delayed, delaying the handover of the CSM to GSDO impacting the ESD Enterprise Schedule.	ESA and Airbus provide weekly reports with schedule risks. In addition, the ESM schedule is updated quarterly and schedule risks are assessed with probabilistic risk assessment.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Acquisition Strategy

NASA is using a competitively awarded contract to Lockheed Martin Corporation for Orion's design development, test, and evaluation. The contract was awarded in 2006, and reaffirmed in 2011 as part of reformulating the Orion Crew Exploration Vehicle as the Orion program. Orion adjusted this contract to meet NASA and HEOMD requirements to include the current flight test plan and the EM-2 flight readiness date. The Orion Program has successfully acquired a Justification for Other than Open Competition for Production and Operations (P&O) beginning with EM-3 and expecting the contract to be in place in FY 2018. The Orion Program released a Request for Proposal from Lockheed Martin for the P&O effort in January 2018.

NASA signed an Implementing Arrangement with ESA to provide service modules for the Orion spacecraft for EM-1 and EM-2. Incorporating the partnership with ESA also required a contract modification with Lockheed Martin to integrate the ESA-provided service module with the Lockheed Martin portion of the spacecraft. Orion is discussing with ESA about their contribution for EM-3 and subsequent missions.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Orion Design and Development	Lockheed Martin	Littleton, CO

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
System Readiness Review (SRR)	Standing Review Board (SRB)	Mar 2007	To evaluate the program's functional and performance requirements ensuring proper formulation and correlation with Agency, and HEOMD's strategic objectives; assess the credibility of the program's estimated budget and schedule.	Program cleared to proceed to next phase.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
SDR	SRB	Aug 2007	To evaluate the proposed program requirements and architecture; allocation of requirements to initial projects; assess the adequacy of project pre-formulation efforts; determine if maturity of the program's definition and plans are sufficient to begin implementation.	Program cleared to proceed to next phase.	N/A
PDR	SRB	Sep 2009	To evaluate completeness and consistency of the program's preliminary design, including its projects, is meeting all requirements with appropriate margins, acceptable risk, and within cost and schedule constraints; determine the program's readiness to proceed with the detailed design phase.	Program cleared to proceed to next phase.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Resynchronization Review	SRB	Jul 2012	The purpose of the review is to realign the program's preliminary design to the current Exploration system development requirements. NASA policies allow changes to a program's management agreement in response to internal and external events. An amendment to the decision memorandum signed at the KDP-B review held before PDR if a significant divergence occurs.	Program cleared to proceed to next phase.	N/A
Delta PDR	SRB	Aug 2014	To update the program's preliminary design; ensures completeness and consistency; determine the program's readiness to proceed with the detailed design phase.	Program cleared to proceed to next phase.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
CDR	SRB	Oct 2015	To evaluate the integrity of the program integrated design. This includes its projects and ground systems, its ability to meet mission requirements with appropriate margins and acceptable risk, planned within cost and schedule constraints; determine if the integrated design is appropriately mature to continue with the final design and fabrication phase for EM-1.	Program cleared to proceed to next phase.	N/A
ESM CDR	SRB	Oct 2016	To evaluate the integrity of the program integrated design. This includes its projects and ground systems, its ability to meet mission requirements with appropriate margins and acceptable risk, planned within cost and schedule constraints; determine if the integrated design is appropriately mature to continue with the final design and fabrication phase for EM-1.	Program cleared to proceed to next phase.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
CIR/System Integration Review (SIR)	N/A	Nov 2016	To evaluate the readiness of the program, including its projects and supporting infrastructure, to begin system AI&T with acceptable risk, and within cost and schedule constraints.	Program cleared to proceed to next phase.	N/A
EM-2 CDR	SRB	Nov 2018	To evaluate the integrity of the program integrated design. This includes its projects and ground systems, its ability to meet mission requirements with appropriate margins and acceptable risk, planned within cost and schedule constraints; determine if the integrated design is appropriately mature to continue with the final design and fabrication phase for EM-2.	N/A	N/A
System Integration Review (SIR)	NA	Feb 2019	To assess risks and plans for starting integration of all hardware into the structure to build up the flight vehicle	N/A	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
System Acceptance Review/Design (SAR) Certification Review	N/A	Apr 2019	The purpose of this review is to evaluate whether a specific end item is sufficiently mature for shipment from the supplier to its designated operational facility or launch site.	N/A	N/A

SPACE LAUNCH SYSTEM

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Launch Vehicle Development	2072.0	2079.3	2072.2	2001.8	2104.3	2071.4	2216.2
SLS Program Integration and Support	55.1	56.1	50.9	61.2	60.9	59.6	59.8
Total in FY19 Budget Structure	**2127.1**	**2135.4**	**2078.1**	**2062.9**	**2165.1**	**2131.0**	**2276.0**
Programmatic CoF in CECR Account	8.8	5.8	25.9	0	0	0	
Exploration Ground Systems	471.9	426.1	428.4	589.9	520.8	458.7	451.9
Total in FY12 Budget Structure	**2607.8**	**2567.3**	**2532.4**	**2652.8**	**2685.9**	**2589.7**	**2727.9**
Change from FY 2018			**-34.9**				
Percentage change from FY 2018			**-1.36%**				

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.

As NASA seeks to expand the boundaries of human space exploration, Space Launch System (SLS) is preparing to carry humans, infrastructure, supporting equipment, and science missions farther into deep space than ever before.

SLS is a critical national capability for exploring the solar system and continuing U.S. leadership in science, technology, and exploration for decades to come. The vehicle’s capabilities will evolve using a block upgrade approach. This will allow the program to increase its initial lift capability from 70 metric tons to over 130 metric tons to beyond Earth orbit and deep space when all upgrades are completed. The Agency will continue to identify and implement affordability strategies to ensure SLS can be a sustainable exploration capability for decades to come.

For further programmatic information, go to: http://www.nasa.gov/exploration/systems/sls/index.html.

Program Elements

SLS PROGRAM INTEGRATION AND SUPPORT

SLS program integration and support activities manage the Orion and EGS program interfaces. This effort is critical to ensuring SLS systems’ performance meets technical and safety specifications, and supports programmatic assessments key to achieving integrated technical, cost, and schedule management. In addition, the SLS integration effort is vital to managing interfaces with other HEOMD activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across the three programs enables the Agency to avoid potential design overlaps, schedule disconnects, and cost issues.

SPACE LAUNCH SYSTEM

LAUNCH VEHICLE DEVELOPMENT

See Launch Vehicle Development section.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023	BTC	Total
Formulation	2674.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	2674.0
Development/Implementation	4698.7	1198.4	949.0	**182.8**	30.0	0.0	0.0	0.0	0.0	7058.9
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2018 MPAR LCC Estimate	**7372.7**	**1198.4**	**949.0**	**182.8**	**30.0**	**0.0**	**0.0**	**0.0**	**0.0**	**9732.9**
Total Budget	**7951.8**	**2072.0**	**2079.3**	**2027.2**	**2001.8**	**2104.3**	**2071.4**	**2216.2**	**0.0**	**22523.9**
Change from FY 2018				**-52.1**						
Percentage change from FY 2018				**-2.5%**						

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Four RS-25 flight engines with their new Engine Controller Units (ECU) preparing for shipment to NASA's Michoud Assembly Facility in New Orleans.

The difference between the total budget and the MPAR LCC estimate is the total budget includes content outside of EM-1 and excludes CoF; LCC only includes EM-1 content, including CoF.

PROJECT PURPOSE

As NASA expands its focus for human spaceflight to destinations across the solar system, the Launch Vehicle Development project will enable deep space exploration with the Space Launch System (SLS) launch vehicle. For the first time since the Apollo program in 1972, American astronauts will be able to explore space beyond low Earth orbit (LEO) and return astronauts to the Moon.

EXPLANATION OF MAJOR CHANGES IN FY 2019

After completing a comprehensive review of the launch schedule, NASA has established an EM-1 integrated launch date of no earlier than December 2019. This date represents a time frame where it is anticipated that a majority of the hardware will be ready to support final launch integration and flight

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

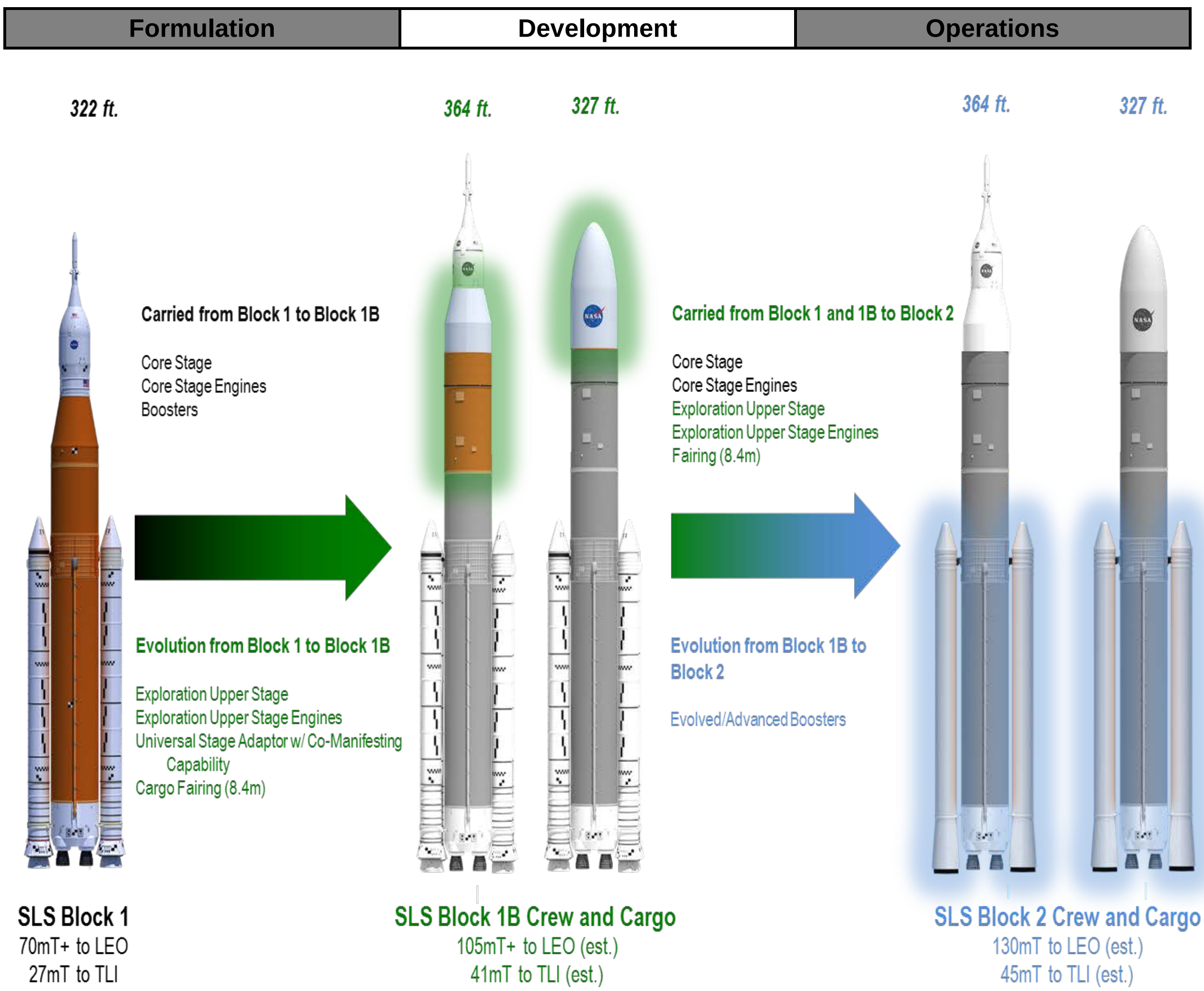
activities. While the review of the possible manufacturing and production schedule indicate a launch date of June 2020, the agency is managing to December 2019. Mitigation strategies to protect the December 2019 date are principally focused on critical path areas related to core stage production and European Space Agency service module delivery.

PROJECT PARAMETERS

Launch Vehicle Development continues work to achieve cost, schedule, and performance goals by leveraging hardware designed for previous programs, including adapted Space Shuttle main engines, five-segment Shuttle-derived solid rocket boosters, and an interim cryogenic propulsion stage (ICPS) using a derivative of the Delta cryogenic second stage. Additionally, development has started for an advanced Exploration Upper Stage (EUS), which will add significantly to the vehicle's lift and in-space capabilities. The program benefits from NASA's half-century of experience with liquid oxygen and hydrogen heavy-lift vehicles, large solid rocket motors, and advances in technology and manufacturing practices.

SLS vehicle design will be flexible and evolvable based on mission requirements. In an effort to achieve schedule and cost efficiencies, each evolution shares the same core stage and while adding an improved upper stage and booster upgrades to increase capability to accommodate more challenging crew and cargo missions. Initially, SLS will exceed its required 70 metric ton lift capability to LEO, and will use its Trans-Lunar Injection (TLI) performance to send nearly 30 metric tons to cislunar space. Current estimates of lift capability to LEO are at 85 metric tons. The first upgrade, adding the EUS, will improve vehicle lift performance to 105 metric tons to LEO and more than 40 metric tons to cislunar space, which will be utilized by launching the Orion crew capsule and co-manifested payloads. Ultimately, with the addition of advanced boosters, SLS could evolve to carry over 130 metric tons to LEO and 45 metric tons to cislunar space. SLS enables an increasing capability to demonstrate deep space technologies and hardware needed for future missions independent of Earth.

LAUNCH VEHICLE DEVELOPMENT



ACHIEVEMENTS IN FY 2017

The vast majority of program content is on track for EM-1, and work is rapidly being transitioned to future flights and planned upgrades. As previously discussed, the program has experienced delays and issues that required a replan of program schedules for EM-1. Some of the most critical issues include first-time production issues for the SLS core stage. Early production issues are not unprecedented for an activity of this scope and ambition.

In FY 2017, SLS completed significant activities, including all major welding operations of the core stage structural sections using the Vertical Assembly Center at Michoud Assembly Facility (MAF). This includes the 130+ foot tall flight liquid hydrogen tank and liquid oxygen tank that will feed the four RS-25 rocket engines during SLS ascent. At Marshall Space Flight Center (MSFC), SLS also completed welding the Launch Vehicle Stage Adapter (LVSA) that connects the ICPS to the core stage. SLS continued conducting multiple development engine tests on the A-1 Test Stand at Stennis Space Center

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

(SSC). The combined lab testing, and hot-fire testing on the A-1 test stand advanced the flight certification of the Engine Controller Units (ECU), which completed in early FY 2018.

SLS continued to develop, test, and integrate flight avionics in the software integration laboratory, allowing development and testing of avionics in an accurate flight-like configured system. Manufacturing and assembly of the flight ICPS was completed and the ICPS shipped to KSC for processing.

Construction of test stands for new core stage structural test article facilities at MSFC was completed with the exception of minor punch list items verifying completion. Additionally, the completed core stage engine section structural test article (STA) shipped by barge from MAF to MSFC for testing. Core stage STA testing, using the new test stands validates adequate structural capability prior to launch. Successful integration and testing of the combined STA LVSA, Orion Stage Adapter (OSA) and the STA ICPS in late spring 2017 led to certification of structural flight worthiness.

WORK IN PROGRESS IN FY 2018

During FY 2018, SLS continues to progress towards EM-1 and concurrently, develop the Block 1B. EM-1 launch vehicle stage adapter and the Orion stage adapter will complete assembly and check out and will ship to KSC in preparation for integration. The EM-1 RS-25 engines, which are now fully completed, will ship for integration to the core stage. The core stage sections will be outfitted with avionics, tested, and begin joining into the full flight core stage.

In addition to making considerable progress towards EM-1 fabrication, qualification, and assembly of flight elements, SLS is making strides towards Block 1B and the EUS that will provide additional power for deep space exploration missions. Ensuring future capabilities, solid rocket motor segments for the EM-2 flight began production and casting of booster segments. Additionally work began on developing the new RS-25 engines for future missions. The RS-25 engines are based on the Space Shuttle Program heritage but achieve a 33 percent cost reduction with innovative and advanced manufacturing methods. The full scale core stage mock up, a Pathfinder for major core stage handling maneuvers, completed in early FY 2018 and will deliver to SSC for B2 test stand confirmation of Core Stage test fit. The remaining minor punch list items of the B2 test stand at SSC will complete and the test stand readied for the Pathfinder and ultimately flight hardware core stage hot fire test. Flight software and related avionic components will continue testing in the software integration laboratory at MSFC. The EUS, a critical component for Block 1B, will complete its Critical Design Review (CDR) and fabrication for future deep space missions will continue. All of the EM-1 booster components including, aft skirt assemblies, and forward assemblies will complete and (along with the already completed segments and nozzle assemblies) will be readied for delivery to KSC.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

FY 2019 will begin with release of the SLS flight software for formal review and certification in preparation for the EM-1 flight. In parallel, the EM-1 Booster flight hardware will deliver to KSC for integration. The EM-1 core stage components including RS-25 engines, the engine section, hydrogen tank, inter-tank, and oxygen tank will complete joining and ship from MAF to SSC for hot fire green run

Formulation	Development	Operations

testing. Green run is the term used for the hot fire testing of the flight core stage with it fully fueled, secured in the test stand at SSC, and tested for the full duration of time as if during real flight. The EM-1 certification for flight relies on the core stage hot fire green run testing scheduled for spring 2019. Upon the successful green run test, the core stage will ship to KSC and complete vehicle certification with the conclusion of the Design Certification Review Board in preparation for the EM-1 Flight Readiness Review.

With all EM-1 SLS hardware at KSC, SLS will support Exploration Ground Systems (EGS) integration operations using a co-developed Design Center concept. SLS will provide subject matter expertise as needed to support vehicle build-up and Integrated Test and Checkout, but will have limited VAB floor presence to minimize potential obstructions to integration flow operations. SLS and EGS will conduct daily meetings to communicate and coordinate integration operations.

With delivery of EM-1 hardware, the SLS program will shift emphasis and the focus to EM-2 and beyond. Payload integration requirements will mature in support of the cargo manifest for long-term exploration and utilization of cislunar space. Fabrication and testing of elements of EM-2 will continue, to include Core Stage, EUS, and certification of restarted production line RS-25 engines, solid rocket booster components, Universal Stage Adapter, and the Payload Adapter. SLS will also deliver four RL-10 engines for integration with EUS. SLS will continue fabrication of the redesigned, more affordable RS-25 engines. A Block 1B major event in FY 2019 is the EM-2 CDR setting the design of components for EM-3, and beyond.

Schedule Commitments/Key Milestones

Milestone	Confirmation Baseline Date	FY 2019 PB Request
KDP-A	Nov 2011	Nov 2011
Formulation Authorization	May 2012	May 2012
SRR/S	May 2012	May 2012
KDP-B Agency Project Management Council (APMC)	Jul 2012	Jul 2012
PDR Board	Jun 2013	Jun 2013
KDP-C APMC	Jan 2014	Jan 2014
CDR Board	Jul 2015	Jul 2015
Design Certification Review	Sep 2017	Oct 2019
EM-1 Launch Readiness	Nov 2018	Dec 2019

While the review of the possible manufacturing and production schedule indicate a launch date of June 2020, the agency is managing to December 2019.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2015	7,021.4	70	2019	7058.9	.005	EM-1 Launch Readiness	Nov 2018	Dec 2019	13

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost. While the review of the possible manufacturing and production schedule indicate a launch date of June 2020, the agency is managing to December 2019.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**7,021.4**	**7058.9**	**37.5**
Stages Element	3,138.7	3708.2	569.5
Liquid Engines Office*	1,198.3	402.1	-796.2
Booster Element	1,090.3	997.9	-92.4
Other	1,594.2	1950.6	356.4

The Agency Baseline Commitment previously included fixed and shared costs with the RS-25 production restart activity (in the Liquid Engines Office) which supports EM-1 and later missions. SLS removed those costs from the estimate and significantly lowered the EM-1 Liquid Engines Office and Current Year Development Cost Estimate.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Booster	Responsible for development, testing, production, and support for the five-segment solid rocket motor to be used on initial capability flights	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC Cost Share Partner(s): N/A	N/A
Engines	Responsible for development and/or testing, production, and support for both core stage (RS-25) and upper stage liquid engines	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC and SSC Cost Share Partner(s): N/A	N/A
Stages	Responsible for development, testing, production, and support of hardware elements, including core and upper stages, liquid engine integration, and avionics integration	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC/MAF, and SSC Cost Share Partner(s): N/A	N/A
Spacecraft Payloads and Integration	Responsible for development, testing, production, and support of hardware elements for integrating the Orion and payloads onto SLS, including the ICPS, Orion stage adapter, LVSA, universal stage adaptor and payload fairings	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC, LaRC, GRC, and KSC Cost Share Partner(s): N/A	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
Given new Propellant, Liner, and Insulation (PLI) materials requirements levied for SLS, and new design and stress state information identified during the QM-1 Aft Segment Investigation, there is the risk that structural & fracture concerns may prevent development of acceptable flight rationale.	New PLI materials have properties that are very different from historical materials. The recent QM-1 Aft Segment Investigation resulted in a PLI system design change to the barrier coating, and found that the cure process may result in insulation mechanical & fracture properties where acceptable EM-1 flight rationale cannot be developed. HEOMD accepted a SLS proposal to remove the barrier coating on future flight segments, complete analysis of the no-barrier design for review at the SLS Design Certification Review (DCR), and continue work on flight rationale for completed segments with the barrier.
Given multiple schedule-related challenges (timeliness of component deliveries, rate of infrastructure development progress, testing impacts, quality structural article testing and hot fire Green Run, and barge availability), one or more of these challenges will result in a schedule delay and associated cost overruns.	Stages process for schedule risk identification, assessment, tracking, and reporting of all top level schedule critical path drivers (with days of negative or positive slack) are reported monthly. Updated mitigation actions are employed as necessary preserving and improving schedule margin. Actions include reallocating budget, increasing activity to parallel paths (schedule resequencing), multi-shifting, later installation, etc. for in-house activities as well as prime contract based efficiencies. Early FY 2018 analysis shows improving trends. Threats and opportunities are addressed on a daily basis.
Given that the SLS program is employing a dynamic test philosophy and methodology different from heritage programs using an integrated dynamic test of the vehicle stack, there is a possibility that prior to EM-1 flight, element or vehicle analyses or tests reveal that math models are insufficient. This characterization model uncertainty may result in the need to repeat virtual modeling analysis and lead to a potential launch delay.	Mitigation is through a building block testing including static & modal tests of Stages, ICPS & MPCV. These individual elements are then integrated into vehicle modal tests including Partial Stack Modal Test (PSMT), Integrated Modal Test (IMT), and Dynamic Rollout Test (DRT). In addition, planning is under way for a full-scale Mobile Launcher only modal test. Results of this test will correlate and update the dynamic flex models to assess impact, if any, on design of the integrated vehicle loads and control systems of the vehicle. If negative impacts arise, they will be assessed as part of flight dynamics risk assessment and mitigated accordingly.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Acquisition Strategy

MAJOR CONTRACTS/AWARDS

Procurement for SLS launch vehicle development meets the Agency's requirement to provide an evolvable vehicle within a schedule that supports various mission requirements. Procurements include use of existing assets to expedite development, and further development of technologies and future competitions for advanced systems and key technology areas specific to SLS vehicle needs.

Element	Vendor	Location (of work performance)
Boosters	Orbital ATK	Magna, UT
Core Stage Engine	Aerojet Rocketdyne	Desoto Park, CA and SSC
ICPS	United Launch Alliance under contract to Boeing Aerospace	Huntsville, AL
Stages	Boeing Aerospace	New Orleans, LA
Upper Stage Engines	Aerojet Rocketdyne	West Palm Beach, FL

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

INDEPENDENT REVIEWS

NASA established an SRB to perform the independent reviews of the Space Launch Vehicle project as required by NPR 7120.5.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PDR	SRB	Aug 2013	To evaluate the completeness/ consistency of the planning, technical, cost, and schedule baselines developed during formulation; assess compliance of the preliminary design with applicable requirements; and determine if the project is sufficiently mature to begin Phase C.	The SRB evaluated the project and determined the project is sufficiently mature to begin Phase C and begin final design and fabrication.	N/A
CDR	SRB	Jul 2015	To evaluate the integrity of the project design and its ability to meet mission requirements with appropriate margins and acceptable risk within defined project constraints, including available resources. To determine if the design is appropriately mature to continue with the final design and fabrication phase.	The SRB evaluated the project and determined the project is sufficiently mature to progress to major manufacturing, assembly and integration.	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
DCR	SLS Independent Review Team	Oct 2019	To certify the implemented design complies with applicable requirements and necessary verification activities are satisfactorily completed.	Certification of the SLS Block 1 design is completed.	N/A
Block 1B Delta CDR	HEOMD Independent Review Team (IRT)	NET Oct 2020	To evaluate the integrity of the Block 1B design and its ability to meet mission requirements with appropriate margins and acceptable risk. To determine if the design is appropriately mature to continue with the final design and fabrication phase.	The IRT will evaluate Block 1B content to assess if the program has achieved sufficient maturity to progress to major manufacturing, assembly and integration.	N/A

EXPLORATION GROUND SYSTEMS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	471.9	--	428.2	589.9	520.8	458.7	451.9

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

The Exploration Ground System (EGS) program enables integration, processing, and launch of the Space Launch System (SLS) and Orion spacecraft. EGS is making all required facility and ground support equipment modifications at Kennedy Space Center (KSC) to enable assembly, test, launch, and recovery of the SLS and Orion flight elements. EGS is also modernizing communication and control systems to support these activities. Upon completion, the KSC launch site will be able to provide a more flexible, affordable, and responsive national launch capability compared to prior approaches.

Program Elements

EGS PROGRAM INTEGRATION AND SUPPORT

EGS program integration and support activities manage the SLS and Orion program interfaces. This effort is critical to ensuring ground systems' performance meets technical and safety specifications and supports the programmatic assessments key to achieving integrated technical, cost, and schedule management. In addition, the EGS integration effort is vital to managing interfaces with other Human Exploration and Operations Mission Directorate (HEOMD) activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across the three programs enable the Agency to avoid potential design overlaps, schedule disconnects, and cost issues.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

See the Exploration Ground Systems Development.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023	BTC	Total
Formulation	965.8	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	965.8
Development/Implementation	934.7	450.0	422.9	**291.1**	79.9	0.0	0.0	0.0	0.0	2178.6
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2018 MPAR LCC Estimate	**1900.5**	**450.0**	**422.9**	**291.1**	**79.9**	**0.0**	**0.0**	**0.0**	**0.0**	**3144.4**
Total Budget	**1671.9**	**458.5**	**426.1**	**423.2**	**575.0**	**505.1**	**443.0**	**442.3**	**0.0**	**4945.2**
Change from FY 2018				**-2.9**						
Percentage change from FY 2018				**-0.7%**						

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

The difference between the total budget and the MPAR LCC estimate is the total budget includes content outside of EM-1 and excludes CoF; LCC only includes EM-1 content, including CoF.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

PROJECT PURPOSE

NASA's upgraded crawler-transporter 2 (CT-2), carrying mobile launcher platform 1, moves slowly along the crawlerway at KSC. The crawler's upgrades and modifications will be monitored and tested to confirm it is ready to support the load of the mobile launcher carrying the SLS with Orion atop for EM-1.

Exploration Ground Systems (EGS) is preparing and launching the Space Launch System (SLS) and Orion space transportation systems. EGS is developing the necessary ground systems while refurbishing and upgrading infrastructure and facilities required for assembly, test, and launch of SLS and Orion, along with the landing and recovery activities of Orion. This includes Pad 39B, the Vehicle Assembly Building (VAB), the Mobile Launcher and other smaller facilities to move from Space Shuttle focused to support exploration missions. The modernization efforts maintains flexibility on Pad 39B and in the VAB in order to accommodate other potential users. Additionally, following the EM-1 launch of SLS and Orion, the Mobile Launcher, VAB, and Pad will undergo modifications to accommodate the upgraded SLS Block 1B.

For more programmatic information, go to http://go.nasa.gov/groundsystems.

EXPLANATION OF MAJOR CHANGES IN FY 2019

After completing a comprehensive review of the launch schedule, NASA has established an EM-1 integrated launch date of no earlier than December 2019. This date represents a time frame where it is anticipated that a majority of the hardware will be ready to support final launch integration and flight activities. While the review of the possible manufacturing and production schedule indicate a launch date of June 2020, the agency is managing to December 2019. Mitigation strategies to protect the December 2019 date are focused in critical path areas related to core stage production and European Space Agency service module delivery.

PROJECT PARAMETERS

EGS is modernizing and upgrading KSC's ground systems and facilities required to enable integration of SLS and Orion, move the integrated vehicle to the launch pad, and launch it successfully into space. For the Exploration Missions (EMs), EM-1 and EM-2, the EGS team is developing procedures and protocols to process the spacecraft, rocket stages, and launch abort system before assembly into one vehicle. Additional work required to launch astronauts into space includes modifying the Mobile Launcher and crawler-transporters; preparing Launch Complex (LC)-39B at KSC, modernizing computers, tracking systems, and other networks.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

ACHIEVEMENTS IN FY 2017

The vast majority of program content is on track for EM-1, and work is rapidly being transitioned to future flights and planned upgrades. As previously discussed, the program has experienced delays and issues that required a replan of program schedules for EM-1. Issues include software development in EGS that are affected by schedule changes from the flight elements. Early production issues are not unprecedented for an activity of this scope and ambition.

At KSC, EGS completed installing and outfitting access platforms in the VAB. The renovation of Launch Pad 39B is progressing well and includes upgrading and modifying the flame trench and environmental control system and installing a new flame deflector. The program successfully tested upgrades to the Crawler-Transporter 2, which included new generators, gear assemblies, jacking, equalizing and leveling hydraulic cylinders, roller bearings and brakes.

The Program is progressing with Verification and Validation (V&V) of the Multi-Payload Processing Facility (MPPF). The MPPF will be used for offline processing and fueling of the Orion spacecraft and service module stack before launch.

The program completed installing five of eight sets of umbilical attach points on the Mobile Launcher including the Orion Service Module Umbilical, Core Stage Intertank Umbilical, Core Stage Forward Skirt Umbilical, Vehicle Support Posts, Aft Skirt Electrical and Pneumatic Umbilicals, completing more than 70 percent of the umbilical and launch accessory deliveries to the Mobile Launcher from the Launch Equipment Test Facility.

The first major integrated operation at Launch Pad 39B at KSC began in September 2017 with the initial filling of the liquid oxygen sphere, a giant sphere that can hold about 900,000 gallons of liquid oxygen. Filling of the liquid hydrogen sphere will start in early November. Hardware delivered to EGS this year included left forward skirt for SLS solid rocket boosters, service platforms for SLS booster engines, and the Interim Cryogenic Propulsion Stage (ICPS).

The program completed upgrades at LC-39B including installing a new communication system; installing new heating, ventilation and cooling systems; replacing water system piping; and installing new ignition overpressure/sound suppression bypass valves. The program completed structural and facility modifications on the Mobile Launcher, and will finish installing ground support equipment in FY 2018. Additionally, the program began initial tanking of a cryogenic fuel into a giant sphere at launch pad 39B to support the launch of Orion spacecraft.

EGS began studies on requirements to support SLS upgrades for EM-2 on the communication systems, the Mobile Launcher, and requiring additional liquid hydrogen capacity at the launch pad.

WORK IN PROGRESS IN FY 2018

The program will complete the System Integration Review, which will evaluate readiness for multi-element V&V. MPFF V&V will be completed in June 2018. Once the program has completed the system

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

verification and validation phase, the program will begin the operations and integration phase in preparation for multi-element V&V for the Mobile Launcher, Pad, and VAB.

Spacecraft offline processing will begin in the third quarter of 2018. During this process, the program will validate all systems hardware and software in order to determine the system readiness for a safe and successful launch.

The program completed the launch accessories remote and end to end testing of the five sets of umbilical attach points on the Mobile Launcher verifying readiness to support the first SLS rocket launch.

During the fourth quarter of FY 2018, the Mobile Launcher will roll into VAB High Bay 3 to start multi-element verification and validation testing with the platforms. Integration operation will begin after the required 24-hour cool-down period on the Mobile Launcher.

Mobile launcher Ground Support Equipment (GSE) and umbilical installation, testing and V&V will be completed in May leading to an integrated multi-element V&V.

Underway Recovery Test (URT) -6, which is the last engineering development URT, occurred off the coast of San Diego in January 2018 aboard a Landing Platform Dock class ship. This will be the first URT to attempt night operations. The test will allow NASA and the U.S. Navy to continue to demonstrate and evaluate the recovery processes, procedures, and hardware before committing to conducting actual recovery operations of the Orion spacecraft and crews at the end of each mission.

The program is continuing to conduct studies on the requirements to support SLS upgrades for EM-2 on communication systems, the Mobile Launcher, VAB and requirements for additional liquid hydrogen capacity at the pad.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

Multi-element V&V of the ground systems will be completed to support the EM-1 launch. The SLS Core Stage and Orion Crew Service Module will be turned over to EGS for ground processing operations and integrated testing. To prepare for the EM-1 launch and operations, the program will complete flight hardware assembly, integration, and testing as well as conduct spacecraft and VAB stacking Operations Readiness Reviews (ORR) and launch pad ORR in anticipation of a certification of flight readiness.

The program will also complete two Underway Recovery Tests to ensure safe recovery of the Orion crew module post the EM-1 mission. In addition, EGS will continue ground systems development efforts in support of SLS Block 1B for EM-2. Designs efforts for Mobile Launcher structural modifications, installation of GSE, VAB HB3/HB4 platforms and Environmental Control System will be completed. Upon design completions, construction activities for the new VAB platforms and the Pad B LH2 new storage tank will begin, as well as fabrications of the new umbilicals necessary to support the new SLS vehicle configuration.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Schedule Commitments/Key Milestones

Milestone	Confirmation Baseline Date	FY 2018 PB Request
KDP-A	Feb 2012	Feb 2012
Formulation Authorization	Apr 2012	Apr 2012
SRR/SDR	Aug 2012	Aug 2012
KDP-B APMC	Nov 2012	Nov 2012
PDR Board	Mar 2014	Mar 2014
KDP-C APMC	May 2014	May 2014
CDR Board	Dec 2015	Dec 2015
SIR	Mar 2018	Mar 2018
EM-1 Launch Readiness	Dec 2019	Dec 2019

While the review of the possible manufacturing and production schedule indicate a launch date of June 2020, the agency is managing to December 2019.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2015	1,843.5	70	2018	2,178.7	18%	EM-1 Readiness	Nov 2018	Dec 2019	13

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost. While the review of the possible manufacturing and production schedule indicate a launch date of June 2020, the agency is managing to December 2019.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**1,843.5**	**2,178.7**	**335.2**
Mobile Launcher	213.1	396.2	183.1
LC-39B Pad	77.5	72.7	(4.8)
VAB	92.7	77.5	(15.2)
Command, Control, and Communications	198.0	395.9	197.9
Offline Processing and Infrastructure	110.2	86.0	(24.2)
Other	1,152.0	1,150.5	(1.5)

**Other includes Crawler Transporter, Launch Equipment Test Facility, Integrated Operations, Program Management, Logistics, S&MA, and SE&I*

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Project Management & Commitments

EGS balances customer requirements among SLS, Orion, and other Government and commercial users. EGS is developing ground systems infrastructure necessary to assemble, test, launch, and recover Orion elements.

Element	Description	Provider Details	Change from Baseline
Ground Systems Implementation (GSI)	GSI is responsible for design, development, build, hardware/software integration, verification and facility systems, and GSE.	Provider: KSC Lead Center: KSC Performing Center(s): ARC Cost Share Partner(s): N/A	N/A
Operations and Test Management (O&TM)	O&TM is responsible for conducting overall planning and execution of both flight hardware and ground systems processing activities.	Provider: KSC Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Command, Control, Communication (C3)	C3 is responsible for development, operation, and sustainment of End-to-End Command and Control and Communications services.	Provider: KSC Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Program Management Team (PMT)	PMT includes project management, safety and mission assurance, logistics, systems engineering, utilities and facility operations, and maintenance.	Provider: KSC Lead Center: KSC Performing Center(s): NA Cost Share Partner(s): N/A	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: There is insufficient time to perform all V&V activities, Then: There is a possibility of a schedule delay to the EGS Operations Readiness Date.	Mobile Launcher team started overlaying updated construction schedule with the V&V schedule. Rescheduling a significant portion of the park site V&V to the VAB, which would affect the overall V&V schedule completion.
If: The Ground Flight Application Software Team (GFAST) internal/external dependencies on GSE subsystems, SCCS, Models and Emulators, SLS, Orion and ICPS to provide requirements, data products and hardware are not within the currently defined GFAST schedule, Then: There is the possibility GFAST will not be ready to perform integrated processing with flight hardware and GSE in the VAB/Pad and MPPF in time to meet Cross-Program objective and schedules while remaining within allocated budgets.	The program approved additional funding for Firing Room assets, which will lower the risk when hardware is installed and available for GFAST use.
If: The programmatic baseline schedule has insufficient time and funding allotted to perform all Launch Accessory testing at the LETF including rework, redesign, regression testing and problem resolution, Then: There is a possibility of not meeting the scheduled program delivery to Mobile Launcher milestone.	Through schedule analysis, LETF has incorporated a work schedule for Launch Accessories with contractor support to mitigate this risk. Monitoring of the risk will continue.
If: The Mobile Launcher GSE installation design is running in parallel with ground subsystem GSE and vehicle designs, Then: There is a possibility that unplanned revisions to the GSE Installation Design will be required and installation construction contract cost and schedules may be significantly impacted. This has a significant impact to the Mobile Launcher operational readiness date to support launch.	Acceleration Schedule is under review by Mobile Launcher team and contractors.

Acquisition Strategy

To retain flexibility and maximize affordability, EGS serves as its own prime contractor for development activities. EGS executes SLS and Orion ground infrastructure and processing requirements by leveraging

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

center and programmatic contracts. For more routine work, EGS also uses pre-qualified Indefinite-delivery, Indefinite-quantity contractors while exercising full and open competition for larger or more specialized projects, such as facility systems construction contracts, and associated GSE fabrication firm-fixed-price contracts. A fixed-price contracting approach is the first choice whenever possible, as it provides maximum incentive for contractors to control costs, since they are subject to any losses incurred. In addition, it imposes a minimal administrative burden upon the contracting parties.

MAJOR CONTRACTS/AWARDS

EGS development activities will encompass projects of varying content and size. EGS does not have a prime contract; it uses the center's institutional contracts to execute the development, engineering, construction and programmatic activities. If the project size or scope falls outside existing center capabilities, then a competitively bid firm-fixed-price contract will be used.

Element	Vendor	Location (of work performance)
Mobile Launcher Structural and Facility Support Modification Contract	J.P. Donovan Construction, Inc.	KSC
VAB High Bay Platform Construction	Hensel Phelps Construction, Inc.	KSC

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
All	SRB	Nov 2012	To provide independent assessment of program technical plan, cost estimates, schedules, and risks at KDP-B	Program cleared to proceed to next phase	N/A
PDR	SRB	Mar 2014	To evaluate completeness and consistency of program preliminary design; determine readiness to proceed with detailed design phase	Program cleared to proceed to next phase	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	**Development**	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
CDR	SRB	Mar 2016	To demonstrate that program design is mature; support full-scale fabrication, assembly, integration, and test; and meet overall performance requirements within cost and schedule constraints.	Program cleared to proceed to next phase	N/A
SIR	KSC Independent Review Team (IRT)	Mar 2018	To evaluate the readiness of the program, including its projects and supporting infrastructure, to begin system Assembly, Integration, and Test with acceptable risk and within cost and schedule constraints.	Program cleared to proceed to next phase	N/A
Block 1B Delta CDR	HEOMD Independent Review Team (IRT)	NET May 2019	To evaluate the integrity of the Block 1B design and its ability to meet mission requirements with appropriate margins and acceptable risk. To determine if the design is appropriately mature to continue with the final design and fabrication phase.	The IRT will evaluate Block 1B content to assess if the program has achieved sufficient maturity to progress to major manufacturing, assembly and integration.	N/A

ADVANCED EXPLORATION SYSTEMS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Lunar Orbital Platform - Gateway	0.0	--	**504.2**	662.0	540.0	558.9	459.1
Advanced Cislunar and Surface Capabilities	0.0	--	**116.5**	146.0	163.7	300.0	320.3
Exploration Advanced Systems	97.8	--	**268.2**	260.7	240.6	186.1	144.7
Total Budget	**97.8**	**--**	**889.0**	**1068.6**	**944.3**	**1045.0**	**924.1**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

In FY 2019, $140M was transferred from AES to Exploration Research and Technology (ER&T) in support of the HRP and $44.680M was transferred to ERT in support of AES Core activities.

NASA team test SAFFIRE II and III components

The Advanced Exploration Systems (AES) division infuses technologies and develops high-priority capabilities using a combination of unique in-house activities and public-private partnerships to develop and test prototype systems that will form the basis for future human spaceflight missions. Public-private partnerships are agreements and contracts that enable NASA and private sector industry and academia to share in the risk and gain of Government investments. These shared risks and gains include incentivizing technical performance, building future commercial markets and a shared financial interest in developing capabilities.

AES will focus on integrating and testing the systems needed for future human deep space exploration. These core areas are funded through three areas: Lunar Orbital Platform - Gateway (LOP-G), Advanced Cislunar and Surface Capabilities, and Exploration Advanced Systems.

The new Lunar Orbital Platform - Gateway (LOP-G) will serve as a platform in cislunar to mature necessary short and long-duration deep space exploration capabilities through the 2020s. The LOP-G will be assembled in orbit around the Moon where it can also be used as a staging point for exploration, science, commercial and international partner missions to the lunar surface and to destinations in deep space. Astronauts on the LOP-G can directly operate rovers and scientific instruments on the Moon. The LOP-G is an important piece of lunar infrastructure and will allow for reusable landers on the surface of the moon and as a location to transfer lunar and possibly Martian samples for return to the Earth. In support of the LOP-G, AES will continue to mature and test capabilities such as habitation capabilities, airlock capabilities, and power and propulsion to provide communication to support astronaut Extravehicular Activity.

In order to enable the cislunar platform, AES will invest in development and demonstration of exploration capabilities to reduce risk, lower life cycle cost and validate operational concepts for future human missions. Under Exploration Advanced Systems (EAS) ground habitation prototypes developed by private-public partnership will be tested to evaluate human factors for different habitat configurations; assess how the various systems interact together and with other capabilities like propulsion modules and airlocks; and provide platforms to test and ensure that standards and common interfaces being considered are well designed.

AES will also invest in Advanced Cislunar and Surface Capabilities (ACSC) to help establish a U.S presence on the Moon. Working in parallel with scientific lunar exploration, NASA is planning to develop a series of progressively more capable robotic lunar missions to the surface of the Moon. This will also serve as a foundational training ground to prepare for later missions to Mars. ACSC will utilize public-private partnerships and international participation to promote innovative approaches to lunar robotics, a cislunar presence, and lunar landing capabilities to enhance U.S. leadership. ACSC will have close collaboration and partnering between HEOMD, Science Mission Directorate, and the new Exploration Research & Technology (ER&T) organization.

The technology capabilities and processes pioneered by AES will enable the first intrepid crews of the new space age to cross countless frontiers, stay safe and healthy, deliver scientific discoveries, and sustain new homes away from home, for the benefit of all humankind.

EXPLANATION OF MAJOR CHANGES IN FY 2019

In FY 2019, Advanced Exploration Systems (AES) is initiating major new program areas to establish a lunar orbital platform - gateway, invest in cislunar and surface capabilities to return humans to the Moon, and advance key capabilities for human habitation.

AES will no longer focus on lower level technology developments for exploration. Low Technology Readiness Level technologies will now be developed through the Exploration Research and Technology organization.

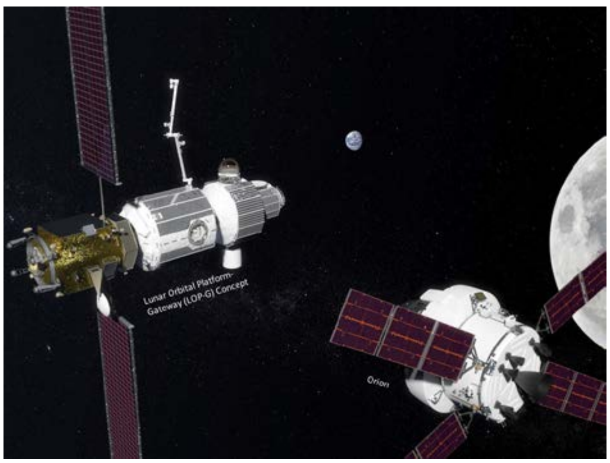
LUNAR ORBITAL PLATFORM - GATEWAY

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**0.0**	**--**	**504.2**	**662.0**	**540.0**	**558.9**	**459.1**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



Orion approaching the Lunar Orbital Platform - Gateway in lunar orbit (notional).

NASA proposes to establish a Lunar Orbital Platform - Gateway (LOP-G) as a platform to mature necessary short- and long-duration deep space exploration capabilities through the 2020s. The LOP-G will be assembled in orbit around the Moon where it can also be used as a staging point for missions to the lunar surface and to destinations in deep space, providing a flexible human exploration architecture. The LOP-G can evolve depending on mission needs, and although there are various concepts for its configuration, current analysis suggests that the initial functionality will include four main elements: a Power and Propulsion Element (PPE), habitation element, airlock element to enable docking and Extra-Vehicular Activities (EVA), and a logistics element for cargo delivery, science utilization, exploration technology demonstrations, and potential commercial utilization.

The PPE is the initial element of the LOP-G, and it will be placed around the Moon by 2022. NASA intends to launch the PPE through a competitive commercial launch contract. The PPE is being developed through partnership with U.S. commercial companies and will demonstrate more powerful solar-electric power (SEP) and propulsion bus systems that will support both NASA and commercial applications. The PPE is intended to supply power and propulsion for additional elements and systems on the LOP-G as well as communication to and from Earth, space-to-space, space-to-lunar, and in support of astronaut EVA. PPE will be refuelable and could support cislunar operations for more than a decade. Once the PPE, habitation, airlock capabilities and sufficient logistics have been delivered to cislunar space, a crew of four - launched on Orion - will visit the LOP-G on missions initially lasting 30 days. As additional habitation capabilities are incorporated (e.g., volume, life support systems, and logistics resupply), crew visits may increase in duration.

Current formulation for the LOP-G includes systems requirements definition, concept of operations, and documentation of a configuration for crew-tended habitation in cislunar space. In addition, the LOP-G will be used as a test bed for critical deep space capabilities such as habitation, life support, radiation

LUNAR ORBITAL PLATFORM - GATEWAY

protection, logistics management, and autonomous mission operations. The LOP-G is an important piece of lunar infrastructure that will allow for reusable landers to the surface of the Moon and as a location to transfer lunar samples for return to the Earth. The operational concepts needed for crew to operate and perform research on the LOP-G will serve as a training ground to develop the knowledge for humans to move into deep space.

EXPLANATION OF MAJOR CHANGES IN FY 2019

While some aspects of the LOP-G program, such as PPE, had been previously funded in Advanced Exploration Systems (AES), this is a new funding line established in the FY 2019 Budget.

ACHIEVEMENTS IN FY 2017

NASA transitioned away from the Asteroid Redirect Mission (ARM) and all relevant work previously conducted on power and propulsion was continued to advance toward a demonstration of that capability in deep space. Activities transitioned from ARM include low-thrust mission design, advanced SEP-based spacecraft bus requirements development, industry spacecraft design studies, and human/robotic mission integration. These activities provide important ground work for the LOP-G PPE and other future deep space exploration objectives.

Using the Next Space Technologies for Exploration Partnerships (NextSTEP) Broad Agency Announcement (BAA), NASA solicited inputs from U.S. industry on their current capabilities and plans that could be leveraged to provide an advanced SEP- based spacecraft bus for the cislunar LOP-G. The request identified 23 topic areas including potential commercial synergies to support development of a PPE. These studies will provide data on U.S. commercial capabilities for PPE while NASA continues to define objectives and requirements as well as how to reduce risk for a new powerful and efficient SEP technology in deep space that will be used on future exploration missions.

WORK IN PROGRESS IN FY 2018

PPE selected five proposals for further industry study from the inputs received in FY 2017. Other progress includes developing PPE requirements and planning for acquisition and partnership approaches in coordination with the Space Technology Mission Directorate (STMD). PPE will award a contract for PPE spacecraft development in FY 2018 and mature design with industry to baseline the preliminary design in early 2019. Critical to this selection process is realization of a deep space operational power and propulsion capability that is directly applicable to wide range of commercial, robotic, and human spaceflight missions.

The NextSTEP Phase 2 Habitation contracts, funded in Exploration Advanced Systems (EAS), to develop prototype deep space habitats are directly applicable to the Lunar Orbital Transport - Gateway. NASA is formulating the LOP-G by defining system requirements, developing design and interoperability standards, establishing program and system-level control boards, developing strategy and execution mechanisms to acquire a PPE, and developing an integrated ground test plan for prototype habitats. The ground prototypes will allow NASA and the NextSTEP habitation partners to: 1) evaluate configurations and habitability attributes of the habitat, 2) assess how the various systems interact together and with other capabilities such as propulsion modules and airlocks, and 3) provide platforms to test and ensure standards and common interfaces being considered are comprehensive and enable the intended interoperability.

At the end of NextSTEP Phase 2 study contracts, the industry partners will provide the functional habitat ground prototype units to NASA for testing. The intended outcome of these activities is a complete set of long-duration deep space architecture designs (including standards, common interfaces, and testing approaches) from the awarded contractors as well as development and test of full-size ground prototypes.

While the NextSTEP Habitation activities are identifying potential U.S. industry implementation approaches and partnerships for the LOP-G, concurrent assessments are underway by the International Space Station (ISS) partners to evaluate alternative approaches for implementation but focusing on international capabilities and contributions as a strategy for the LOP-G buildup in cislunar space.

ISS partner studies provide data on the spacecraft design/interfaces, a cislunar concept of operations, and potential opportunities for international collaboration leveraging current ISS and other partnerships. Results of these studies will inform the development of initial LOP-G requirements and evaluation of potential commercial and/or international approaches.

The acquisition and partnership phase for additional functions/elements of the LOP-G will begin after being informed by NextSTEP-2 contracts and the ongoing discussions with international partners on potential contributions.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

NASA will continue working with the newly-selected PPE industry provider to enable successful delivery of their development schedule. The expected milestones will include design reviews and procurement of long lead items. PPE will work with NASA internal partners to codify deliverables and ensure confirmation baseline is achieved.

Early 2019 ground testing of habitation prototypes will further enable LOP-G habitation design through a demonstrated consistent test and verification approach, allowing NASA to incorporate and test subsystems, facilities, crew training approaches, and receive feedback on human factors.

During FY 2019, NASA will further relationships with both its public and international partners to solidify acquisition and partnership plans. These plans will allow NASA to begin formulation of the remaining functions/elements of the LOP-G.

Program Elements

POWER AND PROPULSION ELEMENT

PPE is the first element of the Lunar Orbital Platform-Gateway (LOP-G). It will provide deep space power and propulsion capability through a public-private partnership that is directly applicable to a wide range of NASA, commercial, robotic, and human spaceflight missions. PPE will leverage U.S. commercially available spacecraft development and launch capability and align with anticipated industry needs. It will provide transportation for the LOP-G between cislunar orbits with the option to perform any needed orbital maintenance. It will provide attitude control for the LOP-G in multiple configurations, communication to and from Earth, space-to-space communication, space-to-lunar communication, and in support of astronaut EVA. PPE will also deliver systems necessary for deep space navigation, docking, and refueling. At the end of the LOP-G operational life, PPE will move the integrated LOP-G stack to a disposal orbit.

PPE works with U.S. industry to utilize deliverables from STMD (which will be part of the new Exploration Research & Technology [ER&T] organization) in Advanced Electric Propulsion Systems (AEPS). It will demonstrate an advanced SEP system, including ER&T- developed 12.5 kW AEPS thrusters and power processing units, and advanced high power solar array systems. PPE will use SEP technology to insert itself into cislunar orbit and provide overall station-keeping for the LOP-G and will move the LOP-G into different low gravity lunar orbits depending on mission requirements and will provide high-bandwidth communications. PPE has a targeted launch readiness of 2022.

HABITATION ELEMENT

The LOP-G habitation element provides a livable section and short-duration life support functions for the crew in cislunar space. The docking ports allow for attachment to the PPE, other elements and visiting vehicles. The habitat also provides attach points for external robotics, external payloads or rendezvous sensors; thermal radiators provide heat rejection and micro-meteoroid protection; and additional habitat systems provide accommodations for crew exercise, science/utilization and stowage. Some functions may be outfitted via future logistics flights.

LOGISTICS ELEMENT(S)

NASA is currently assessing specific configurations and strategy for unpressurized logistics delivery, refueling, commercial launch vehicle pressurized logistics, and the Space Launch System (SLS) pressurized logistics. All potential concepts deliver cargo to the LOP-G to enable extended crew mission durations, science utilization, exploration technology demonstrations, potential commercial utilization, and other supplies.

AIRLOCK ELEMENT(S)

The airlock element provides the LOP-G with the capability to enable astronaut EVAs as well as the potential to accommodate docking additional elements, observation ports, or a science utilization airlock.

Multiple concepts are currently being assessed and feasibility studies have identified several different approaches ranging from small, single chamber airlocks to large, dual chamber airlocks with inflatable crew locks.

LUNAR ORBITAL PLATFORM - GATEWAY

Program Schedule

The LOP-G elements and final configuration are still in the formulation phase. During FY 2018, NASA will make significant progress on the establishing milestones, program implementation assignments, and acquisition strategy.

Date	Significant Event
Q2-3 FY 2019	PPE Design Milestone I
Q1-2 FY 2020	PPE Design Milestone II
Aug 2022	PPE Launch Readiness Date (LRD)

Program Management & Commitments

HEOMD executes LOP-G activities, and the Directorate's Associate Administrator has delegated management authority, responsibility, and accountability of the habitation element, airlock element(s), and logistics element(s) to the AES Division at NASA Headquarters. The management authority, responsibility, and accountability of the PPE is delegated to the PPE Program Director.

The AES Division has established cross directorate control boards to manage the direction of scope, budget, and resource allocation for all activities. These control boards include representation by the PPE Program, ISS Program and the Exploration Systems Division (ESD) programs. Cross program systems integration is managed through the extensive use of ESD program board and review processes and membership.

Program Element	Provider
Power and Propulsion Element	Provider: NASA Centers Lead Center: GRC Performing Center(s): GRC and JSC Cost Share Partner(s):
Habitat	Provider: TBD Lead Center: TBD Performing Center(s): TBD Cost Share Partner(s): TBD
Logistics	Provider: TBD Lead Center: TBD Performing Center(s): TBD Cost Share Partner(s): TBD
Airlock	Provider: TBD Lead Center: TBD Performing Center(s): TBD Cost Share Partner(s): TBD

Acquisition Strategy

PPE selected industry studies from the umbrella NextSTEP BAA Appendix C submittals. NASA will acquire a PPE during FY 2018 through full and open competition for a public-private partnership to demonstrate advanced SEP capability for both NASA and U.S. industry objectives. NASA intends to launch the PPE through a competitive commercial launch contract. Acquisition plans for the additional functions/elements of the LOP-G will be determined over the course of FY 2018 and 2019 as required and will utilize full and open competition, public-private partnerships, and international partnerships.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
PPE (planned for FY 2018)		
Habitat (planned for FY 2019)		

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PPE Independent Review	GSFC-chaired, NASA members	Jul 2017	Independent review to support HEOMD DPMC decision to proceed	Passed	PPE SRR

ADVANCED CISLUNAR AND SURFACE CAPABILITIES

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	0.0	--	116.5	146.0	163.7	300.0	320.3

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Vice President Mike Pence speaks in front of the space shuttle Discovery at the National Air and Space Museum's Udvar-Hazy Center to open the first meeting of the reconstituted National Space Council. Credit: NASA/Joel Kowsky

NASA is pursuing a new campaign in Advanced Cislunar and Surface Capabilities (ACSC) that will once again establish U.S. preeminence to, around, and on the Moon. Working in parallel with scientific lunar exploration, and in addition to the initial flights of the Space Launch Systems (SLS), Orion, and the elements of the Lunar Orbital Platform – Gateway, NASA is planning to develop a series of progressively greater robotic lunar missions to the surface of the moon. This will also serve as a foundational training ground to prepare for later missions to Mars. Utilizing commercial and international participation to enhance U.S. leadership, ACSC will focus on engaging non-traditional U.S. industry partners and sectors in the space program and will use innovative approaches to combine lunar robotics, a cislunar presence, and lunar landing capabilities. NASA will also partner with international partners as appropriate in this endeavor.

Partnering with the Science Mission Directorate's (SMD) new Lunar Discovery and Exploration Program's activities, including support for commercial landed services, ACSC activities will focus on continued growth of emerging commercial capabilities to further enhance lunar lander capabilities and utilization of our nearest neighbor. ACSC will also partner with the Space Technology Mission Directorate (STMD) (which will be part of the new ER&T organization) to acquire lower level commercial technologies that can continue to be developed for future lunar missions.

This will be accomplished through public-private partnerships with the emerging commercial industry and innovative approaches to achieving human and science exploration goals. The Exploration Campaign under the SMD Lunar Discovery and Exploration Program will support activities such as establishing initial commercial contracts for transportation services with a maximum payload range likely up to 200 kg, developing small rovers to be delivered via commercial landers, as building and launching instruments that serve lunar science, long-term exploration and utilization needs. ACSC will solicit, engage, and nurture growing capabilities beyond those initial landing capabilities and progress to a large commercial lander in the 5000kg class, heading towards lunar utilization and a human landing long term.

ADVANCED CISLUNAR AND SURFACE CAPABILITIES

EXPLANATION OF MAJOR CHANGES IN FY 2019

AES is pursuing a new campaign in Advanced Cislunar and Surface Capabilities (ACSC) that will with other Exploration Campaign activities establish U.S. preeminence to, around, and on the Moon.

ACHIEVEMENTS IN FY 2017

N/A.

WORK IN PROGRESS IN FY 2018

In FY 2018, ACSC will partner with SMD on a Request for Information (RFI) regarding emerging commercial capabilities, short and long term mission plans, information on what commercial sector opportunities there are that would be enabled through regular access to the lunar surface, and innovative public-private partnership acquisition approaches.

This RFI will be followed by a solicitation to support joint risk reduction activities. Using a new appendix under the Next Space Technologies for Exploration Partnerships (NextSTEP) Phase 2 Broad Agency Announcement, NASA will solicit from industry lander risk reduction activities and concepts that start with an initial capability of landing a minimum of 500kg payload(s) to the lunar surface. The solicitation will also seek to identify how these activities are extensible to larger lander capabilities in excess of 5-6000kg payload(s) to the lunar surface including what human landing risk reduction can be accomplished with the proposed landers.

These activities will be closely coordinated with SMD and the Lunar Discovery and Exploration Program so that NASA ensures continued options to on-ramp new commercial landing capabilities as the readiness of those services becomes available and economically sustainable.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

Accomplishments from the AES division's Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) partnerships will be assessed to evaluate efforts that are likely directly linked to ACSC. The CATALYST partnerships encourage development of robotic lunar landers that can be integrated with U.S. commercial launch capabilities to deliver payloads to the lunar surface.

In 2019 ACSC will incorporate results of the 2018 industry RFP for Commercial Lunar Payload Services being led by SMD, Lunar CATALYST outcomes, and the planned FY 2018 RFI regarding emerging commercial capabilities to support initial risk reduction activities. Through a NextSTEP solicitation in FY 2018 ACSC will begin initial planning of a series of robotic demonstration missions expected to start at the 500kg payload class in the early half of 2020, with an expectation to start developing larger (5-6000kg) class payloads in the latter 2020s. This timeline will be adjusted based on results from industry feedback and inputs from the previously noted industry engagements.

ADVANCED CISLUNAR AND SURFACE CAPABILITIES

Program Elements

LUNAR ROBOTIC LANDERS

While we have extensive orbital information about the lunar surface and potential resources, landing on the Moon validates prior observations and is essential to prepare for utilization by NASA, international partners, and the commercial sector, including landing humans. Robotic landers will play an instrumental role in obtaining this "ground truth" data. Not only can landers be outfitted with sensor packages, they can also provide lunar surface access for rovers that can explore the surface more extensively, as well as carry instruments such as In-Situ Resource Utilization experiments that will provide detailed information on extraction of usable resources such as oxygen. In addition to obtaining this information, robotic landers can provide critical risk reduction activities for the human-scale lander descent stage and utilization capabilities.

To accomplish these exploration activities, demonstration landers will be needed, with the capability to deliver payloads in the ~500 kg range to the lunar surface to obtain information on a diverse set of surface locations to be identified for potential utilization. These landings will be in addition to extensive landing missions to be planned and conducted by the SMD led Lunar Discovery and Exploration Program. These demonstration missions will also prove out key requirements such as landing precision, long-term survivability, guidance and navigation for larger-class size landers.

After landing the 500kg class landers, NASA is envisioning a ~5-6000 kg lander that will be capable of preparing for more extensive exploration and utilization of the lunar surface. This class of lander is required for larger scale exploration and utilization and systems, and also supports progress toward human ascent vehicles.

Program Schedule

The specific schedule for the Advanced Cislunar and Surface Capabilities efforts is still in the formulation phase and needs to be informed primarily by commercial responses to planned industry engagements. During FY 2018, NASA will make significant progress on establishing milestones, program implementation assignments, and acquisition strategy beyond the initial engagements.

Date	Significant Event
Feb 2018	Issue RFI with SMD Lunar Exploration Discovery Program
March 2018	Issue NextSTEP BAA Appendix for initial risk reduction capabilities
2019	Award proposals from NextSTEP BAA

ADVANCED CISLUNAR AND SURFACE CAPABILITIES

Program Management & Commitments

HEOMD will execute the Advanced Cislunar and Surface Capabilities activities.

SMD will lead the Agency's Lunar Discovery and Exploration Program.

Program Element	Provider
TBD	Provider: TBD Lead Center: Performing Center(s): JSC, JPL Cost Share Partner(s): TBD

Acquisition Strategy

NASA plans to use a variety of options to engage U.S. domestic industry and international partners.

MAJOR CONTRACTS/AWARDS

N/A and TBD

INDEPENDENT REVIEWS

N/A

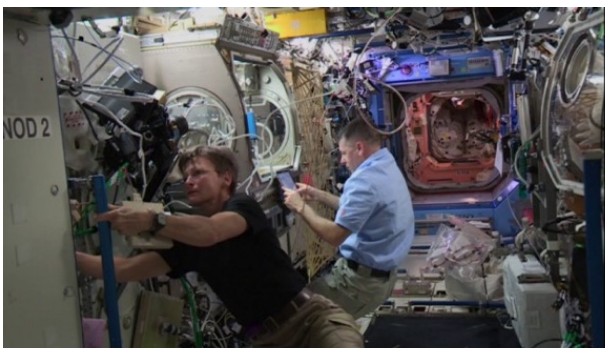
EXPLORATION ADVANCED SYSTEMS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	97.8	--	268.2	260.7	240.6	186.1	144.7

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



Astronaut Peggy Whitson installing 1 of 24 RFID-Enabled Autonomous Logistics Management (REALM)-1 antennas to track inventory on ISS.

Exploration Advanced Systems (EAS) focuses on design, development, and demonstration of exploration habitation capabilities technologies to reduce risk, lower life cycle cost and validate operational concepts needed for future deep space habitation elements, including the Lunar Orbital Platform-Gateway (LOP-G). EAS leads development of new approaches to project and engineering management, such as rapid systems development or alternative management concepts, open innovation, and collaboration.

The Agency identifies and addresses potential risks by performing early validation and ground/flight testing of new capabilities prior to integration into planned operational systems. Early risk reduction can minimize cost growth and improve affordability of future space exploration. For example, NASA is advancing a phased approach to habitation systems development that includes initial ground testing of capabilities and subsequent demonstration and operations of fully realized systems on the International Space Station (ISS). NASA continues to leverage core capabilities, technology developments, and innovative approaches among Agency organizations including Human Exploration and Operations Mission Directorate (HEOMD), Space Technology Mission Directorate (STMD) (which will be part of the new Exploration Research & Technology [ER&T] organization), Office of the Chief Technologist (OCT), Science Mission Directorate (SMD), and implementing field centers nationwide, to maximize combined capabilities and future outcomes. EAS performs an integrating function drawing from the entire cross-cutting technology development activities that support LOP-G.

EXPLANATION OF MAJOR CHANGES IN FY 2019

EAS concentrates on development of systems, sub-systems, and fundamental capabilities for Orion, SLS, Exploration Ground Systems (EGS), LOP-G and Advanced Cislunar and Surface Capabilities programs (ACSC). It relies on STMD for lower Technology Readiness Level (TRL) options for integration and infusion to increase system maturation.

EXPLORATION ADVANCED SYSTEMS

EAS is no longer pursuing a potential independent Resource Prospecting (RP) mission, but integrating the RP measurement objectives with SMD Lunar Discovery Exploration Program and lander capability advancements under the Advanced Cislunar and Surface Capabilities programs.

ACHIEVEMENTS IN FY 2017

Released in April 2016, NASA issued an omnibus Next Space Technologies for Exploration Partnership (NextSTEP)-2 Broad Agency Announcement (BAA), in which Appendix A sought continued development of habitation system concepts and technologies with the goal of developing full-size cislunar habitat ground prototypes by 2019. Additionally, NextSTEP-2 seeks to:

- Mature design of the overall deep space integrated system(s) and, at a minimum, develop a full size, ground prototype for integrated testing of form, fit, and partial functions of the design.
- Achieve level of fidelity in concepts for confidence that protoflight vehicle(s)/modules can be produced for flight in the early to mid-2020s.
- Stimulate commercial capabilities for low Earth orbit (LEO), enable capability development that intersects NASA long-duration deep space habitation requirements and commercial LEO habitation.
- Develop long-duration deep space habitation capabilities that lead toward a deep space habitat and can be flown on SLS flight(s) (or alternative launch vehicles) starting by the early to mid-2020s.
- Develop and mature Government-furnished equipment (GFE) for ECLSS, avionics, exercise equipment, soft goods, radiation detection and protection, and windows.

Throughout the NextSTEP-2 performance phase, NASA is providing GFE and systems, as well as NASA personnel expertise to each of the performers. During this phase, NASA is leading the effort to develop standards and common interfaces, and will develop an internal reference architecture to support the next acquisition phase.

The intended outcome of activities under Appendix A is a diverse set of complete deep-space architecture designs (including standards, common interfaces, and testing approaches) from the awarded contractors, and development and test of full-size ground prototypes of selected units using co-developed and agreed upon standards and common interfaces.

EAS completed three NextSTEP Phase 1 concept studies for various aspects of ECLSS. The ECLSS Modularity Study identified top-level technology candidates and developed a concept for modularized, palletized ECLSS architecture to develop system-level efficiencies. A Hybrid Life Support System study developed a Green wall system that is a prototype fresh food production system that also augments life support systems needed for long duration exploration missions. A third effort encompassed development of a microfluidics based technology to separate CO2 from spacecraft cabin air.

EAS also demonstrated an evolvable Radio Frequency Identification (RFID) Enabled Autonomous Logistics Management (REALM-1) system on ISS to autonomously track inventory and locate missing items.

EAS successfully completed the first three Saffire (Spacecraft Fire Safety) series of experiments, to better understand large-scale fire propagation in space. In FY 2017, EAS also completed the Concept Design Review of the next series of Saffire experiments that will focus on fire suppression and detection options for future exploration missions.

EXPLORATION ADVANCED SYSTEMS

EAS continued Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) partnerships with three companies to develop commercial lunar landing capabilities. The purpose of these partnerships is to encourage development of robotic lunar landers for integration with U.S. commercial launch capabilities and deliver payloads to lunar surface. Lunar CATALYST represents another step in the Agency's effort to spur growth in both the commercial space and lunar sectors. These partnerships were extended two years (through 2019) to support subsequent ACSC milestone.

EAS completed a flight test of a Navigation Doppler Lidar and a Lander Vision System on a STMD sponsored Flight Opportunities Program lander to enable autonomous precision landing capabilities for future robotic and manned missions.

WORK IN PROGRESS IN FY 2018

As NASA works to extend human space exploration to the Moon, EAS will continue developing reliable life support systems, deep space habitats, landing capabilities, and overall capabilities to reduce logistics requirements to support future human spaceflight missions. A portion of the overall Habitation Systems development includes technology options for atmosphere revitalization that includes carbon dioxide (CO2) removal and reduction, as well as oxygen generation activities. EAS will develop and demonstrate a Condensing Heat Exchanger to remove water from the air and work other upgrades to the ISS water recovery system such as mature technologies for brine water recovery. Demonstrating miniaturized atmosphere monitoring systems will enhance monitoring capabilities on ISS and will be extensible to future exploration missions. Trace contamination control measures will be implemented using a combination of charcoal/HEPA filters.

EAS will integrate an RFID Enabled Autonomous Logistics Management (REALM-2) mobile measurement system with the STMD developed Astrobee free flyer to track inventory and locate missing items on board ISS. Also, to be demonstrated on ISS, EAS will continue development and integration of the Universal Waste Management System, which is a compact toilet for use on Orion and the Lunar Orbital Platform-Gateway.

Building on the data acquired through the first three Spacecraft Fire Safety (Saffire) experiments, EAS will continue maturing the next set of experiments to demonstrate large-scale fire suppression, detection and post-fire clean up.

EAS will complete a flight unit of an amine based carbon dioxide removal system that is an alternate approach to the current zeolite-based sorbent systems. This thermal amine based system is capable of recovering water while removing CO2.

EAS will continue to support development of Orion by delivering Ascent Abort-2 (AA-2) flight test article in summer of 2018. AA-2 flight test in April 2019 will demonstrate the launch abort system as the spacecraft breaks through the speed of sound while using AES approach for lean project management, and testing AES-developed avionics and core flight software planned as systems for future capabilities.

EAS will continue managing GFE items for integration with NextSTEP Habitation Phase 2 contractors including avionics, windows materials, and radiation analysis and managing NASA-developed node/airlock and/or habitation mockups for testing with the contractor modules during NextSTEP ground testing in FY 2019.

EXPLORATION ADVANCED SYSTEMS

The avionics GFE effort is providing hardware and expertise in areas of architecture definition and simulation and test support. The team will develop reference avionics and software architecture that is highly reliable and fault-tolerant, and can be scaled and customized to support NASA goals beyond LEO. This architecture will support modular integration of multi-vendor and international partner avionics components, by leveraging open interface standards, both wired and wireless, and human-rated, reconfigurable and open-source software.

The ECLSS GFE effort will entail completing cislunar ECLSS schematic, control architecture and pallet designs while defining impacts to Interface Standards and Specifications.

A potential breakthrough on habitation structures is currently being researched by EAS. Bigelow Expandable Activity Module (BEAM) experiment is currently flying on ISS and collecting data on the characteristics of inflatable structures in space. Further research (e.g., burst tests, creep tests) is required to better understand properties of softgood structures. In addition, EAS is developing modeling approaches that will support human rating certification of these new structures.

Another NextSTEP-2 GFE area is establishing a windows material database for use by internal NASA and external users. The overall goal of this activity is to produce a material properties database which will allow for transition of technology to spacecraft designers and enable them to produce lightweight window systems in future spacecraft.

Radiation GFE work is focused on advancing protections against solar particle events and galactic cosmic radiation in habitation and vehicle systems design by providing assistance and subject-matter expertise to contractors performing radiation analysis and design trades for radiation protection. Through these exchanges, NASA will also provide background materials related to methods for performing radiation analysis; previous NASA radiation storm shelter studies; and guidance for storm shelter design.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

EAS will deliver highly reliable life support systems to deploy on ISS and Orion such as a Brine Processor to recover water from urine and a Spacecraft Atmospheric Monitor to measure atmospheric constituents and contaminants in the ISS air.

NASA selected six proposals under the NextSTEP-2 BAA to develop prototype cislunar habitats and to further study exploration enabling strategies for habitation. The estimated period of performance begins in FY 2018 and extends until FY 2019. Over the course of NextSTEP-2, NASA teams will also be working in parallel with contractor teams to achieve Phase 2 scope of work and prepare for receipt of the prototypes. These areas of activity include architecture analyses, ground test planning, advancing NASA-developed habitation subsystems, and collaboration on development of standards and common interfaces.

One of the primary goals for NextSTEP Habitation Phase 2 is to develop a deep space habitat with representative systems for ground-based testing. Ground prototypes will allow NASA and NextSTEP-2 habitation partners to: 1) evaluate habitat configurations, 2) assess how systems interact together and with other capabilities such as propulsion modules and airlocks, and 3) provide platforms to test and ensure standards and common interfaces being considered are well designed. At the end of Phase 2, the full-size ground prototype units will be delivered by NextSTEP contractors to NASA Centers.

EXPLORATION ADVANCED SYSTEMS

Once delivered, NextSTEP will manage integration of NASA-developed habitation systems and sharing of government developed testing data – GFE items including exercise equipment, avionics, softgoods, ECLSS, windows materials, radiation analysis – and may also use a NASA-developed node/airlock and/or habitation mockups for testing with contractor modules.

The NextSTEP phase 2 ECLSS will deliver a fully functional prototype of a control architecture with intelligent systems incorporated, along with a full set of high fidelity form and fit mockups that demonstrate reparability, as well as a functional Air Revitalization System (ARS) prototype. The effort also includes system engineering support to the other habitation teams and support in defining exploration systems development standards

Another facet of NextSTEP Phase 2 habitation work is developing standards and common interfaces for deep space habitation systems. The systems and elements that are required for Phase 1 and 2 missions in deep space will need to work together and be certified for spaceflight. NASA is working to define a set of standards that will enable NASA, commercial and international partners to contribute systems for deep space. An iterative process is planned to develop a set of standards that includes external feedback from industry and international partners. The set includes interoperability, engineering, safety and mission assurance, and human system standards.

NASA is leveraging the ISS partnerships with other countries to gather international input in the standards development as well as NextSTEP industry partnerships for domestic commercial inputs. Internal to NASA, a cross-functional working group is leveraging lessons learned from existing efforts such as Commercial Crew and ISS programs with a focus on existing standards and their applicability to deep space habitation and transportation architecture.

The working group and standards development process will take an iterative approach that will include an external feedback loop from industry as well as international partners throughout NextSTEP-Phase 2.

Program Elements

Strategic technology infusion element areas drive NASA's Exploration Advanced Systems program within the AES Division, each focusing on a specific capability required for future human space exploration.

HABITAT CAPABILITIES AND SYSTEMS

Habitation Capabilities and Habitation Systems provide fundamental support to ensure a safe place for astronauts to carry out NASA's missions in space and on other worlds, with integrated life support systems, radiation protection, fire safety, and systems to manage food, waste, clothing, and tools. NASA's AES division oversees the Agency's habitation strategy and serves as the central management authority for LOP-G and EAS program. In this capacity, EAS has significant interfaces between the external NextSTEP partners and internal stakeholders, including STMD (which will be part of the new ER&T) and the ISS, Orion SLS and Space Communications and Navigation programs.

EAS focuses on developing key habitation systems to enable the crews to live and work safely in deep space for missions lasting up to one thousand days. Activities include the Bigelow Expandable Activity Module (BEAM), NextSTEP deep space habitation efforts, reliable life support systems, logistics reduction, and radiation measurements and protection. These investments will progressively move from habitation subsystems to integrated systems and then transition to capabilities to define, design, and develop future habitation capabilities and systems for use in exploration missions.

Through NextSTEP Habitation effort, NASA and industry will establish public-private partnerships allowing NASA to leverage their capabilities and investigate enabling NASA habitation needs from LEO commercialization activities through development and testing of a deep space habitation systems. The multiple phases of NextSTEP are informing NASA’s acquisition strategy for its deep space, long-duration habitation capability to be completed and executed under the Lunar Orbital Platform-Gateway implementation.

EXPLORATION ADVANCED SYSTEMS

In the area of EAS, technologies are enhancing the transport of people and payloads across the solar system. Technologies include multiple destination extensible lander technology and module crew launch abort systems These activities which will benefit future robotic and human missions by improving autonomous precision landing on planetary surfaces, as well as potential new propellants and/or propulsion systems. NASA shares these landing capabilities through public-private partnerships with industry through multiple partnership and contract mechanisms.

Program Schedule

Date	Significant Event
CY 2018-2019	First flight of Lunar CATALYST partner lander(s)
Feb 2019	Deliver five NextSTEP prototype habitats to NASA centers for ground testing
Mar 2019	Complete ground testing of NextSTEP prototype habitats
Apr 2019	Ascent Abort – 2 flight test for Orion
Feb 2019	Complete in-flight component change out design, Build/Test Brass Board & Air Revitalization System Demonstrator ECLS Pallet
Mar 2019	Deliver flight units of life support technologies for air revitalization, water recovery and environmental monitoring

Program Management & Commitments

HEOMD executes EAS activities, and the Directorate’s Associate Administrator has delegated management authority, responsibility, and accountability to the AES Division at NASA Headquarters. AES Division establishes overall direction and scope, budget, and resource allocation for activities implemented by the NASA centers.

EXPLORATION ADVANCED SYSTEMS

AES, STMD (which will be part of the new ER&T), and the Planetary Science Division within SMD jointly fund robotic precursor activities, developing instruments to include on NASA's science and international missions. EAS coordinates with the STMD and SMD on Robotic Precursors planning and execution.

Program Element	Provider
Habitation Capabilities and Systems	Provider: NASA Centers Lead Center: HQ Performing Center(s): JSC, MSFC and JPL Cost Share Partner(s): Bigelow Aerospace, Boeing, Lockheed Martin, Orbital ATK, Sierra Nevada, and NanoRacks (NextSTEP)
Exploration Advanced Systems	Provider: NASA Centers Lead Center: HQ Performing Center(s): JSC, MSFC, and JPL Cost Share Partner(s):

Acquisition Strategy

EAS selected initial activities through an internal competition in which NASA centers submitted proposals specifically to address the highest priority capabilities for human exploration beyond LEO. Each year, EAS evaluates how the portfolio aligns with human exploration priorities and technology gaps, and either terminates activities that do not demonstrate adequate progress or realigns them, and/or adds new activities to the portfolio as appropriate. Teams are provided limited procurement funding to purchase materials, equipment, and access and coverage of NASA test facilities. EAS strives to maximize specialized skills within the civil service workforce, but may also utilize a small amount of contractor effort in areas where NASA can cost effectively leverage external skills and knowledge.

EAS continues to increase the use of competitively selected external awards and public-private partnerships. For example, in FY 2015 EAS awarded 12 NextSTEP BAAs, allowing NASA to pursue public-private partnerships for advanced habitation and life support, high-power electric propulsion systems testing, and small satellites for launch on SLS. EAS continued with additional Phase-2 competitive awards in 2016 for development of prototype habitats.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Habitat Systems: Universal Waste Management System	United Technologies Aerospace Systems	JSC
Habitat Systems: Inflatable Module	Bigelow Aerospace	North Las Vegas, JSC
Habitation Systems: Brine Water Processor	Paragon	Tucson Arizona, MSFC

EXPLORATION ADVANCED SYSTEMS

Element	Vendor	Location (of work performance)
Vehicle Systems: Lander Capabilities	Moon Express, Astrobotic Technologies, and Masten Space Systems	MSFC, JSC, and KSC
NextSTEP BAA Awards	Boeing, Bigelow Aerospace, Lockheed Martin, Orbital ATK, Dynetics,	JSC, MSFC, KSC

INDEPENDENT REVIEWS

EAS undergoes quarterly Directorate Program Management Council reviews and periodically, representatives from the Office of Chief Engineer, the Office of Safety and Mission Assurance, and the Office of Chief Financial Officer will assess EAS performance during Agency-level Baseline Performance Reviews (BPR). In addition, EAS provides briefing reports to, and seeks feedback on planning and development activities from the NASA Advisory Council Human Exploration and Operation Committee and the Technology Committee.

EXPLORATION RESEARCH AND TECHNOLOGY

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Early Stage Innovation and Partnerships	89.7	--	**108.4**	103.0	107.0	107.0	107.0
Technology Maturation	135.0	--	**216.5**	178.6	180.8	183.3	183.5
Technology Demonstration	262.8	--	**332.7**	293.1	286.9	284.4	284.2
Human Research Program	140.0	--	**140.0**	140.0	140.0	140.0	140.0
SBIR and STTR	199.0	--	**205.0**	198.0	198.0	198.0	198.0
Total Budget	**826.5**	**820.8**	**1002.7**	**912.7**	**912.7**	**912.7**	**912.7**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

EXPLORATION RESEARCH AND TECHNOLOGY

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Early Stage Innovation and Partnerships	89.7	--	**108.4**	103.0	107.0	107.0	107.0
Technology Maturation	135.0	--	**216.5**	178.6	180.8	183.3	183.5
Technology Demonstration	262.8	--	**332.7**	293.1	286.9	284.4	284.2
Human Research Program	140.0	--	**140.0**	140.0	140.0	140.0	140.0
SBIR and STTR	199.0	--	**205.0**	198.0	198.0	198.0	198.0
Total Budget	**826.5**	**820.8**	**1002.7**	**912.7**	**912.7**	**912.7**	**912.7**
Change from FY 2018			**181.9**				
Percentage change from FY 2018			**22.2%**				

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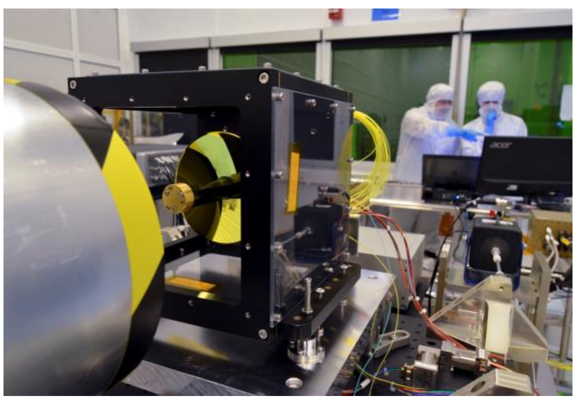


An engineer examines the gimbal and latch assembly component of one of the Laser Communication Relay Demonstration's two optical module assembly. The optical module, when combined with the modems and controller electronics, make up the flight payload. The demonstration mission payload is slated for delivery in June 2019, with a NET Nov. 2019 launch.

The Exploration Campaign will be enhanced and enabled by new technologies. NASA’s workforce, in concert with industry and academia, will focus on innovative ways to further humankind’s exploration from conception to testing to spaceflight.

The FY 2019 President's Budget includes a new account structure for NASA's human space exploration and technology programs to improve alignment of funding with the Administration's new strategic space exploration objectives. The new Exploration Research and Technology account consolidates and refocuses the technology development program content previously funded in the Space Technology and Exploration accounts, including the Human Research Program and elements of Advanced Exploration Systems.

A driving requirement of the Exploration Research and Technology strategy is to serve as a key technology and risk reduction provider for NASA's exploration missions. This means investment in research and development across the Technology Readiness Level spectrum and developing technologies to a flight hardware readiness state with the objectives of increasing performance, reducing risk, and increasing affordability and reliability. It also means developing the scientific and technological expertise to send humans into deep space for longer durations through cutting edge research on space flight and the space environment on the human body.

EXPLORATION RESEARCH AND TECHNOLOGY

Exploration Research and Technology activities will focus primarily on the following areas, which are central to the Exploration Campaign:

- Advanced environmental control and life support systems & in-situ resource utilization (ISRU);
- Power and propulsion technology (including space fission reactors, nuclear thermal propulsion, and high powered solar electric propulsion);
- Advanced materials;
- Communications, navigation and avionics (including laser communication, disruption tolerant networking and high performance spaceflight computing);
- Entry, descent and landing (including Lander technologies);
- Autonomous operations;
- In-space manufacturing and on-orbit assembly; and
- Research to enable humans to safely and effectively operate in various space environments.

This account will use a combination of unique in-house activities, procurements, NASA Research Announcements and public-private partnerships to develop and test technologies to enable space exploration missions. Public-private partnerships will enable NASA to share the risk and financial interest with private sector industry to better leverage government investments. These shared risks and gains include incentivizing technical performance and spurring future commercial markets in the process of developing new capabilities. U.S. technological leadership remains vital to our national security, economic prosperity, and global competitiveness. The Nation's continued economic leadership is, in part, due to the technological investments made in earlier years, through the work of the engineers, scientists, and policy makers who had the wisdom and foresight to make investments our country required to emerge as a global technological leader. That commitment accelerated the economy with the creation of new industries, products, and services that yielded lasting benefits. A technology-driven NASA will continue to fuel our Nation's economic engine for decades to come.

EXPLANATION OF MAJOR CHANGES IN FY 2019

Exploration Research and Technology consolidates the technology development content previously funded in the Space Technology account with Advanced Exploration Systems (AES) and the Human Research Program (HRP), into a single account, integrating these activities toward supporting deep space exploration. The FY 2019 budget is restructured to align with the Administration's new space exploration policy by consolidating and refocusing existing NASA technology development activities on space exploration. The technology focus areas noted above will be prioritized within the portfolio as FY 2018 and FY 2019 activities are phased out or otherwise concluded, and will tilt the portfolio emphasis towards technologies that benefit deep space exploration. The image below represents the consolidation of content within the Exploration Research and Technology as it stands today. This structure will be further refined once NASA finalizes the restructuring to align with our focus on accelerating human exploration beyond low-Earth orbit.

EXPLORATION RESEARCH AND TECHNOLOGY

FY 2018 Structure		
Space Technology Mission Directorate		
	Agency Technology & Innovation	
	SBIR/STTR	
	Space Technology Research & Development (STR&D)	
		Restore-L
		LCRD
Human Exploration and Operations Mission Directorate		
	Exploration	
		Advanced Exploration Systems Core – Foundational Systems, Robotic Precursor, Vehicle Systems, and Strategic Ops, Integration & Studies
		Human Research Program

FY 2019 Structure		
Exploration Research & Technology		
	Early Stage Innovation and Partnerships	
		Agency Technology and Innovation
		Early Stage Innovation (includes AES)
		Partnerships and Technology Transfer (includes AES)
	Technology Maturation (includes AES)	
	Technology Demonstration	
		Restore/In-Space Robotic Servicing (ISRS)
		Laser Comm Relay Demonstration (LCRD)
		Solar Electric Propulsion (SEP)
		Small Spacecraft, Flight Opportunities & Other Tech Demonstration (includes AES)
	Human Research Program	
	SBIR and STTR	

ACHIEVEMENTS IN FY 2017

Successfully entered into the implementation phase for Laser Communication Relay Demonstration to support a 2019 Launch Readiness Date. Set to fly as a hosted payload on the Air Force STPSat-6 mission, this project will demonstrate an order of magnitude leap in communications capability that could be used for the architecture that succeeds NASA's Tracking and Data Relay Satellite (TDRS) or by other government agencies and commercial space communications providers.

AES demonstrated on-demand manufacturing, recycling, and sanitizing of a urine funnel using the ReFabricator, an SBIR phase III technology developed by Tethers Unlimited, Inc, that produces feedstock from recycled plastic parts for an integrated 3D printer. In-space manufacturing can greatly reduce the inventory of spare parts and tools that are needed on long missions. The Human Research Program (HRP) conducted approximately 18 ISS biomedical research investigations during each ISS mission increment, completed seven flight investigations, and initiated three new research investigations. In addition, HRP delivered a real-time crew performance assessment tool, which should prove useful in gathering near real-time human factors and habitability data during spaceflight missions that can be applied to the designs of next generation spacecraft and habitats.

In FY 2017, Space Technology Mission Directorate completed ground testing of the Deep Space Optical Communications technology to retire risk for its demonstration flight. This technology will provide high bandwidth communications for deep space on an upcoming Discovery Program mission. technology.

Flew 17 technology payloads across eight Flight Opportunities campaigns: three parabolic, three high-altitude balloon and two low-altitude rocket-powered entry, descent and landing tests. One of which included a flight test of a Navigation Doppler Lidar and a Lander Vision System to enable autonomous precision landing capabilities for future robotic and manned missions.

The Space Technology Mission Directorate selected the Boeing Company in St. Louis for the High Performance Spaceflight Computing Processor contract. This processor will provide 75 times the computing power over the current state-of-the-art radiation hard computers while enabling more effective power and fault management. Boeing will provide prototype radiation hardened multi-core computing processor Chiplets, system software which will operate on them, and evaluation boards to allow Chiplet test and characterization.

Centennial Challenges awarded more than $1.5 million in FY 2017 for solutions toward the Cube Quest, 3D Printed Habitat and the Space Robotics Challenges.

The Space Technology Mission Directorate selected two Space Technology Research Institutes led by a consortium of universities that will focus on the development of technologies critical to extending human and robotic exploration deeper into our solar system. These institutes will bring together researchers from various disciplines and organizations to collaborate on the advancement of cutting-edge technologies in bio-manufacturing and high performance space structures utilizing transformative composite materials, with the goal of creating and maximizing Earth-independent, self-sustaining exploration mission capabilities.

WORK IN PROGRESS IN FY 2018

The Solar Electric Propulsion project is fabricating engineering development units for the high power, magnetically-shielded Hall effect thrusters. As part of ongoing work under the NextSTEP-1 awards, AES plans to conduct vacuum chamber tests of high-power electric propulsion systems operating for 100 continuous hours and power levels 20 times greater than current technology.

Made in Space Inc., Orbital ATK, and Space Systems Loral will complete the ground based portion of the In-Space Robotic Manufacturing & Assembly public-private partnerships aimed at reducing risks associated with robotic manipulation of structures and remote manufacture of structural trusses. NASA will evaluate the progress and determine readiness to proceed with a Phase II flight demonstration.

The Space Technology Mission Directorate (which will be part of the new Exploration Research & Technology (ER&T) organization) will complete testing of a 1kW nuclear fission reactor that is scalable to a 10kW-class system that would provide abundant energy for surface exploration. The Kilopower project will conduct full ground testing at design temperatures in early FY 2018 at the Nevada National Security Site.

Upon a successful launch in FY 2017, the Station Explorer for X-Ray Timing and Navigation project will demonstrate deep space navigation capability in FY 2018.

Building off the successful FY 2016 demonstration of an integrally stiffened cylinder on a sounding rocket, the Space Technology Mission Directorate (which will part of the new ER&T) will characterize a scaled up, 10-foot diameter integrally stiffened cylinder using the Advanced Near Net Shape technology. This technology uses innovative metal forming techniques to manufacture integrally stiffened aerospace structures such as cryogenic tanks. The resulting product is 50 percent lower cost and 10 percent lighter weight due to fewer welds and minimized machining.

Astrobee will complete ground testing and will deliver a flight unit to the International Space Station (ISS). Once on-orbit commissioning is complete, Astrobee will replace the Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES). Astrobee builds on the success of SPHERES, NASA’s first generation free-flyer now aboard the ISS that can take on research, housekeeping, and monitoring duties without astronaut supervision.

EXPLORATION RESEARCH AND TECHNOLOGY

Among a host of supported activities, the Space Technology Mission Directorate delivered spacecraft for three small satellite missions enabling advanced communications technologies for NASA and industry application. The Optical Communications and Sensory Demonstration and the Integrated Solar Array and Reflectarray Antenna satellites began their mission in December 2017 after successful launch via OA-8 Cygnus (Orbital ATK) in November. The CubeSat Proximity Operations Demonstration will launch later in FY 2018 to demonstrate autonomous rendezvous and docking capabilities for small spacecraft.

The Deep Space Atomic Clock (DSAC) is a small, low-mass atomic clock based on mercury-ion trap technology that will be demonstrated in space, providing unprecedented stability needed for next-generation deep space navigation and radio science. DSAC offers the promise of 50 times greater accuracy than today's best deep space navigation clocks and will rideshare as part of the U.S. Air Force STP-2 mission aboard a SpaceX Falcon Heavy booster. Riding along is NASA's Green Propellant Infusion Mission that will demonstrate a propulsion system using a significantly less toxic propellant than hydrazine provides 40% higher performance by volume. The launch of both DSAC and GPIM is slated for mid-2018.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

FY 2019 will serve as a transition year to allow for evaluating existing investments and prioritize new investments in order to maximize alignment to the Agency's Exploration Campaign, with emphasis on:

- advanced environmental control and life support systems & ISRU;
- power and propulsion technology (including space fission reactors,
- nuclear thermal propulsion, and high powered Solar Electric Propulsion);
- advanced materials technology; communications, navigation and avionics technology (including laser communication, disruption tolerant networking and high performance spaceflight computing);
- entry, descent and landing (including lander technologies);
- autonomous operations;
- in-space manufacturing and on-orbit assembly technology; and
- research to enable humans to safely and effectively operate in various space environments.

In addition, NASA will initiate the following Technology Demonstrations within this five year budget horizon. (These technologies recently completed major milestones indicating maturity for the next level of technology readiness.)

- Cryogenic Fluid Management,
- Precision Landing,
- Rapid Transit Propulsion, and
- Kilopower.

Upon completion of hardware build, system integration and test in FY 2018, the Laser Communications Relay Demonstration project will deliver the completed mission payload to support a FY 2019 Launch Readiness Date.

EXPLORATION RESEARCH AND TECHNOLOGY

NASA will build on its ground demonstration of In-Space Robotic Manufacturing and Assembly through the continued use of public-private partnerships to conduct a flight demonstration for new technologies used to build large structures in a space environment.

The eCryo project will complete its Structural Heat Intercept-Insulation-Vibration Evaluation Rig (SHIIVER) testing in May 2019 before handing off that technology to interested stakeholders in support of NASA's Exploration activities and industry. This test will demonstrate the effectiveness of new multi-layer insulation and evaluate the potential benefit of using vapor vented from a propellant tank to intercept heat coming into the tank through structural elements.

Upon a successful launch and on-orbit operations of the Green Propellant Infusion Mission, the Space Technology Mission Directorate (which will be part of the new ER&T) will complete demonstration of the Air Force developed hydroxyl ammonium nitrate propellant formula, thrusters, and the integrated propulsion system, establishing a higher performing, safe alternative to highly toxic hydrazine. In addition, Deep Space Atomic Clock project will demonstrate space clock navigational accuracy improvements for deep space and provide a technology to improve gravity science measurements.

NASA will complete and deliver ten CubeSats including eight which will fly as secondary payloads on SLS. NASA will also deliver a NASA-sponsored instrument for the Korean Aerospace Research Institute (KARI) lunar mission, Korea Pathfinder Lunar Orbiter (KPLO), This instrument, ShadowCam, will capture low-light images of the Moon's permanently shadowed regions to search for evidence of frost or ice deposits.

In FY 2019, NASA will implement the ISS flight research plan critical to mitigation crew health and performance risk for exploration and will complete ground testing of an advanced exploration exercise system in preparation for ISS deployment as part of exploration system maturation plans. The Human Research Program will also continue to work with Deep Space Exploration’s Habitation development to define and evaluate deep exploration system habitats. Additionally, NASA will continue to leverage resources through multiple partnerships including international partnering on isolation, confinement and physiology studies with Russia, NASA/German Aerospace Center (DLR) and European Space Agency.

NASA will complete a number of Mars 2020 technology developments including Terrain Relative Navigation, Mars Oxygen ISRU Experiment, Mars Environmental Dynamics Analyzer, and the Mars 2020 Entry, Descent and Landing Instrumentation with deliveries between Fall 2018 and Spring 2019 to support the Mars 2020 schedule.

NASA will continue to partner with researchers across academia and industry, and explore transformative technologies and approaches. Upcoming Early Stage Innovation activities will investigate areas such as breakthrough propulsion, challenges in deep space human habitation, space-optimized energy systems, radiation protection, and materials. These areas are part of a comprehensive approach to efficiently support innovative discovery, progress toward important goals, and the development of exciting new capabilities.

EXPLORATION RESEARCH AND TECHNOLOGY

Programs

EARLY STAGE INNOVATION AND PARTNERSHIPS

This program funds early stage research and development sourced from academia, industry, entrepreneurs, and from the NASA workforce to bring pioneering approaches to the Agency's difficult and far reaching exploration challenges. It also supports several Agency integration functions, including technology transfer and technology commercialization activities, extending the benefits of NASA's technology investments so they have a direct and measurable impact. By leveraging industry for technology development that could aid NASA's missions, this approach ensures that NASA technologies energize the commercial space sector and provide the greatest benefit to the United States.

TECHNOLOGY MATURATION

Within Technology Maturation, NASA focuses on advancing disruptive space technologies from a proof of concept to demonstration, maturing transformational technologies across the critical gap that resides between early stage research and flight demonstration. Technologies are prioritized for alignment with NASA's Exploration Campaign objectives.

TECHNOLOGY DEMONSTRATION

The Technology Demonstration portfolio supports ground-based testing to determine feasibility, and technology flight demonstrations in relevant environments to effectively transition technologies for NASA missions and for use by other government agencies and industry. Ground and flight demonstrations are prioritized to enhance and enable deep space human exploration.

HUMAN RESEARCH PROGRAM

The Human Research Program is responsible for understanding and mitigating the highest risks to astronaut health and performance to ensure crews remain healthy and productive during long-duration missions beyond low Earth orbit.

SBIR AND STTR

Small Business Innovation Research and Small Business Technology Transfer continues to support early-stage research and mid-Technology Readiness Level (TRL) development, performed by small businesses through competitively awarded contracts. These programs produce innovations for both government and commercial applications. SBIR and STTR provides the high technology, small business sector with opportunities to develop space technology for NASA and commercialize those NASA-funded technologies that have the potential to address national needs in the aerospace industry and other sectors. Annual solicitations will align subtopics to exploration focus areas to draw on small business support of NASA's Exploration Campaign objectives.

EARLY STAGE INNOVATION AND PARTNERSHIPS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**89.7**	**--**	**108.4**	**103.0**	**107.0**	**107.0**	**107.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

The Foster + Partners | Branch Technology team from Chattanooga, Tennessee, with their 3D-printed dome structure after it was strength tested Aug. 26, 2017, at Caterpillar Inc.'s Edwards Demonstration and Learning Center in Peoria, Illinois. The team won first place and $250,000 at Phase 2: Level 3 of NASA's 3D-Printed Habitat Challenge.

In support of the Exploration Campaign, Exploration Research & Technology (ER&T) integrates the early stage technology research and development previously funded within the Space Technology account and foundational activities of the Human Exploration and Operations Mission Directorate's Advanced Exploration Systems (AES) division with a primary focus on exploration requirements. This integrated program consists of investments in Early Stage Innovation, Technology Transfer, Prizes and Challenges (including Centennial Challenges) and Agency Technology and Innovation (AT&I). Together, these efforts spur collaboration with innovators across the Nation, to capitalize on the ideas, talent and experience of a diverse set of contributors to achieve NASA's exploration objectives.

Early Stage Innovation supports applied research, and early technology development to spur innovation and transform future capabilities. By leveraging the technical capabilities of the experts across the nation, from academia, industry, entrepreneurs, to the NASA Centers, the Agency gains new ideas and alternative approaches to solving NASA's difficult and far reaching exploration challenges.

NASA funds prize competitions and challenges as well as citizen science and other open innovation tools as appropriate to support NASA's R&D objectives and to enhance the agency's connections with the American and global public. This includes Centennial Challenges, the NASA Tournament Lab, NASA Solve, and Innovation Connector (iTech) to leverage high public interest and support on NASA's Exploration objectives.

EARLY STAGE INNOVATION AND PARTNERSHIPS

NASA responds to Administration priorities and legislative requirements to promote technology transfer, including commercialization of technologies that emerge from NASA's research and development activities.

NASA's AT&I funds the operations of the Office of the Chief Technologist (OCT), which manages Agency technology strategy, and promotes innovative culture and partnerships within and outside of NASA.

EXPLANATION OF MAJOR CHANGES IN FY 2019

The new ER&T organization's Early Stage Innovation and Partnerships integrates content from STMD's early stage technology R&D and foundational activities in AES division (including NASA Tournament Lab and Space Synthetic Biology research). Investments will be focused on Exploration Campaign support, which includes research and technologies applicable to deep-space exploration, prioritizing environmental control and life support; power and propulsion; advanced materials; communications; navigation and avionics, robotic assembly and manufacturing; entry, descent and landing; autonomous systems and enabling humans to live and work in the space. In order to focus resources on the exploration key focus areas, the Regional Economic Development activity will be discontinued.

ACHIEVEMENTS IN FY 2017

- Selected two multi-disciplinary university-led research institutes to increase collaboration and advance technologies in bio-manufacturing for deep space exploration, and high-performance materials development for ultra-high strength lightweight structures.
- Selected two Early Career Initiative proposals, each led by an early career civil servant. One is a space byproduct recycling project at the Kennedy Space Center, and the other is an Autonomous Guidance and Control System for Deployable Entry Vehicles at the Ames Research Center.
- Received national recognition through the work of Dr. Marco Pavone from Stanford University who was named a recipient of the prestigious Presidential Early Career Award for Scientists and Engineers in January 2017 for his novel guidance framework. His work included real-time, efficient and dependable algorithms for spacecraft autonomous maneuvering, with a focus on dynamic and highly cluttered environments.
- Through continuous improvement of the Technology Transfer program, accelerated and increased the amount of technology shared with industry through streamlined and automated processes, a reduction in policy hurdles, amplified interactions with industry, and new tool deployment. With year-after-year increases in the technology transfer to the public, NASA has managed a 341 percent increase in annual licensing totals and a 373 percent increase in software release since FY 2011. Last year, there were 109 patent licenses and 5,054 software releases. These outcomes represent a significant return on the taxpayer investment in NASA technology: jobs created, revenue generated, new products to market, and improved quality of life.
- The Office of the Chief Technologist established the NASA Technology Executive Council Working Group, to provide a forum for representatives from across NASA to jointly work in developing collaborative products addressing crosscutting technology policy, portfolio and other issues related to agency technology.
- Centennial Challenges awarded more than $1.5 million in FY 2017 for solutions toward the Cube Quest, 3D Printed Habitat and the Space Robotics Challenges.

EARLY STAGE INNOVATION AND PARTNERSHIPS

WORK IN PROGRESS IN FY 2018

- As of FY 2018 first quarter, there are approximately 430 Early Stage technologies, each with, potential to enable or enhance the next generation of capabilities within and beyond NASA. Recently awarded Early Stage Innovation grants included: Advanced Coating Technology for Space Fission Power and Propulsion Systems; Crosscutting Technologies for Extremely High Frequency Band Space Applications; and Lightweight Multifunctional Lattice Materials for Space Structures. Additional solicitations, aligned with the Exploration key focus areas, will be awarded in all Early Stage elements.
- Centennial Challenges will initiate a challenge targeting the manufacture of "food" for microbial bioreactors from CO2 and hydrogen molecules (CO2 to Sugar Challenge).
- NASA's iTech initiative identified 10 finalists to present innovative ideas that address important problems here on Earth and also holds great potential to overcome critical technology hurdles in future space exploration. NASA facilitated a forum for these entrepreneurs to present their solutions to the Agency and potential industry partners. Over the last 12 months, many of the top 18 companies that have participated in past NASA iTech forums have reportedly raised more than $50 million in private investments to further develop their technologies.
- Technology Transfer will continue to streamline and automate internal processes in order to increase ability to conduct outreach to industry. Technology Transfer also intends to work to broaden outreach to areas that have typically not felt the NASA presence, as well as continue to improve and explore new existing tools to maximize use of online marketing of our portfolios.
- The Office of the Chief Technologist continues to coordinate the interagency Science and Technology Partnership Forums, bringing together leaders from the aerospace, defense, science and technology federal teams to look for areas to partner of mutual interest and priority. Through collaborations, NASA is gaining insight into other federal science and technology policy and investment priorities, using that knowledge to forge federal and American commercial partnerships.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

For solicitations announced in FY 2019, NASA will prioritize investments towards proposals that align with NASA's Exploration Campaign objectives, with emphasis on: advanced environmental control and life support systems and ISRU; power and propulsion technologies for exploration; advanced materials technology; communications, navigation and avionics technologies; entry decent and landing (including lander) technologies; autonomous operations; and in-space manufacturing and on-orbit assembly technologies.

- In addition to issuing the annual solicitations for NASA Innovative Advanced Concepts (NIAC), Space Technology Research Grants and Center Innovation Fund, NASA will select up to two additional research institutes to enable new technologies and capabilities that lay groundwork to enhance and enable deep space exploration. Early Stage Innovation will be aligned with the Exploration focus areas, investigating areas such as breakthrough propulsion, challenges in deep space human habitation, space-optimized energy systems, radiation protection, and materials.
- NASA plans to introduce additional Centennial Challenges with potential topics aligned to deep space exploration focus areas, such as scalable solutions to support humans inside a lunar or planetary habitat, and autonomous monitoring technology for detection and identification of microorganisms in spacecraft.

EARLY STAGE INNOVATION AND PARTNERSHIPS

- In FY 2019, the Office of the Chief Technologist will refine the Agency's space technology taxonomy and Technology Integration Framework that will be used to inform the next NASA Strategic Technology Investment Plan and any future technology roadmaps. By assuring a consistent technology taxonomy among the NASA directorates and offices, the OCT will help to better coordinate and guide the agency's aerospace technology investment strategy.
- The Technology Transfer Program will continue to streamline and automate internal processes in order to increase our ability to conduct outreach to industry as well as continue to explore new and improve existing tools to maximize use of online marketing of our portfolios.

Program Elements

EARLY STAGE INNOVATION

It is not always clear which efforts will result in breakthroughs, effective improvements, or exciting new approaches. This process is nonlinear and takes time. This is why a balance of Early Stage, mid-Technology Readiness Level (TRL), and technology demonstration investments is critical for an effective technology development portfolio.

Exploration Research and Technology's Early Stage Innovation activities employ various approaches to engage technical experts at universities, companies, independent labs, NASA centers, and other government agencies. Through a steady cadence of competitive solicitations, NASA continuously develops new and innovative high-risk/high-payoff technologies. Early Stage studies cultivate new ideas and alternative approaches, and leverage the technical capabilities of the experts across the nation can fuel economic growth. Technologies are often developed with support and coordination between NASA and various external partners, and will primarily focus on innovative ways to further humankind’s exploration from conception to testing to spaceflight. NASA awards early stage efforts through Space Technology Research Grants (STRG), NASA Innovative Advanced Concepts (NIAC), and the Center Innovation Fund (CIF), which are described more in depth below:

- Space Technology Research Grants conducts a series of annual and biannual competitive solicitations targeting high-priority technology areas that challenge the entire spectrum of academic researchers, from graduate students to early career and senior faculty members, making space activities more effective, affordable, and sustainable. In the process, close collaborations between U.S. universities and NASA are fortified. Since its inception, Space Technology Research Grants has funded exciting space technology research via 525 grants - at 106 universities across 43 states and one U.S. Territory. In FY 2017, NASA made 13 Early Stage Innovations awards, eight Early Career Faculty awards and 64 NASA Space Technology Research Fellowship awards. One success from these awards was the work done by Scott Hall from the University of Michigan who demonstrated three new records (101 kW thruster power, 250A operating current and 5.3N thrust) for Hall thruster operations using the new 100kW X3 nested, three-ring thruster. In addition, NASA awarded the inaugural Space Technology Research Institutes; these multi-university, multidisciplinary institutes strengthen NASA’s ties to the academic community through long-term, sustained investment in research and technology development critical to NASA’s future. The Center for Utilization of Biological Engineering in Space, led by the University of California, Berkeley, is advancing research into an integrated, multi-function, multi-organism bio-manufacturing system to produce fuel, materials,

EARLY STAGE INNOVATION AND PARTNERSHIPS

pharmaceuticals and food in space. The Institute for Ultra-Strong Composites by Computational Design, led by Michigan Technological University, aims to develop and deploy a carbon nanotube-based, ultra-high strength, lightweight aerospace structural material within five years. Exploration Research and Technology plans to release another research institute solicitation in FY 2018, with awards made in early FY 2019.

- NASA is making investments today to shape the building blocks needed for the missions of tomorrow. As such, NASA will continue to enable exploration through its investment in synthetic biology applications. This effort was previously managed by Advanced Exploration Systems. As existing efforts conclude, this subject matter will be strategically integrated within the rest of the early stage portfolio.
- NASA Innovative Advanced Concepts executes annual solicitations seeking exciting, unexplored, technically credible new concepts that could one day “change the possible” in space and aeronautics. These efforts improve the Nation’s leadership in key research areas, enable far-term capabilities, and spawn disruptive innovations that make space exploration more effective, affordable, and sustainable. Phase I and continuation Phase II solicitations are open to NASA centers, other government agencies, universities, industry, and individual entrepreneurs. In 2017, NASA Innovative Advanced Concepts made 15 Phase I and seven Phase II awards across industry, academia, and NASA centers, while completing 13 Phase I and seven Phase II studies. The 2016 Phase II Fellow Robert Youngquist continued to show promising results for an in-space fuel tank coating that enables passive cryogenic propellant storage. If successful, this could change the way NASA plans future missions.
- Center Innovation Fund provides annual seed funding to all ten NASA Centers to stimulate aerospace creativity and grassroots innovation to transform future missions and advance the Nation’s capabilities. Center Innovation Fund activities are competitively selected to explore alternative approaches or develop enhanced capabilities that will feed into NASA's Deep Space Exploration objectives. Partnerships with academia, private industry, individual innovators, as well as other NASA Centers and government agencies are highly encouraged. An integrated review of all Center Innovation Fund candidates is conducted to ensure a strategic and coordinated portfolio. These investments have led to multiple successful NASA and commercial applications. One such project is the VESGEN 2D project. VESGEN 2D (VESsel GENeration Analysis 2D) is an interactive piece of software that provides visualization of small blood vessels and surrounding tissue. The project has led to enhanced examinations of astronauts’ eyes on orbit and better understanding of the results through improved visualization. One CIF project led to the conversion of VESGEN from a 2D to 3D visualization tool, leading to even better understanding of the medical data. The project has advanced beyond Center Innovation Fund to the Technology Maturation project to both improve the software and improve the medical scans that feed the software. This combination will not only improve astronaut ocular health but it will provide better medical visualization tools for use throughout the world.

NASA continues to enhance its involvement with academia and its field centers to access unique ideas with breakthrough potential. In upcoming solicitations, NASA will place an emphasis on selecting topics that align and enhance the Exploration focus areas. It is expected that this comprehensive approach will most efficiently lead to discovery and development of exciting new capabilities.

EARLY STAGE INNOVATION AND PARTNERSHIPS

PRIZES AND CHALLENGES (INCLUDES CENTENNIAL CHALLENGES)

NASA seeks to advance space exploration and aeronautics technologies using a variety of methods. In addition to developing technologies in-house as well as through grants, contracts, cooperative agreements and public-private partnerships, NASA has recognized the value of incentivizing new technology advancement and problem solving through “open innovation” approaches including the use of prize competitions and challenges open to the public. Government and non-government organizations have demonstrated the value of prize competitions for their ability to tap into new sources of talent they have not typically reached as well as to make payments only once they have received satisfactory solutions to meet their needs. To further enhance program effectiveness, NASA integrates the Advanced Exploration Systems (AES) NASA Tournament Lab (NTL) and the Prizes and Challenges activities previously funded within the Space Technology account.

NASA utilizes the NASA Tournament Lab (NTL) to facilitate the use of crowdsourcing to tackle Agency challenges. NTL offers a wide variety of open innovation platforms that engage the crowdsourcing community in challenges to create the most innovative, efficient and optimized solutions for specific, real-world challenges being faced by NASA and other Federal Agencies.

NASA works to promote strategic use of prize competitions and challenges as well as citizen science and other open innovation tools as appropriate to support NASA’s R&D objectives and to enhance the agency’s connections with the American and global public. NASA achieves this by examining and taking actions to strengthen NASA policies and infrastructure to support prizes and challenges and other open innovation approaches.

Centennial Challenges offers incentive prizes to generate revolutionary solutions aimed to support future NASA missions. The program seeks innovations from diverse and non-traditional sources by directly engaging the public in the process of developing advanced technology. Competitors are not provided government funding for their development; rather, awards are only made to successful teams when the challenges are met. The program partners with organizations inside and/or outside of NASA to manage challenges with the goal of maximizing return on investment to the agency.

The Centennial Challenges program is formulating additional challenges with available prize funding, and requests an additional $2 million in new prize authority (no-year funding). In the near-term, the team is finalizing formulation of a challenge that seeks to incentivize the development of technologies needed to manufacture "food" for microbial bioreactors from CO2 and hydrogen molecules, abundant on Mars and in space habitats, to produce the sugar glucose. Producing glucose will allow in situ microbial production systems to generate products needed to support future missions, such as food, nutrients, fuels, medicines, plastics and adhesives.

Other potential challenge topics include demonstrating scalable solutions to support humans inside a lunar or planetary habitat, and designing and building autonomous monitoring technology for detection and identification of microorganisms in a spacecraft during a long duration mission.

The following Centennial Challenges are funded and in progress:

- Cube Quest Challenge - NASA’s first in-space challenge, the objective of this challenge is to advance communication and propulsion technologies for small spacecraft. Prizes will be awarded based on the distance the cubesats go in space, and how long they can communicate with Earth as they travel. Before getting a ride to space, participants faced a series of four Ground Tournaments that will assess cubesat communication and propulsion technologies capable of operating in lunar orbit and deep space. The winners of Ground Tournament Four, the last phase of the ground part of the challenge, were announced in June 2017. Three teams won $30,000 each and were selected to join 10 other cubesats as secondary payloads on the first integrated flight of NASA's Orion spacecraft and SLS rocket. The next phase of the challenge will start once the cubesats reach lunar or deep space orbits. Teams will be competing for a share of more than $4 million to be awarded to the cubesats that communicate for the longest period of time with Earth and/or travel the farthest from Earth.

- 3D Printed Habitat Challenge - The purpose of the 3D Printed Habitat Challenge is to advance additive construction technology to create sustainable housing on Earth and beyond. Phase 2 of the challenge was opened in 2016 with Bradley University as the Allied Organization. Caterpillar, Bechtel, and Brick & Mortar Ventures are providing the facilities and required funding support for the competition. Three qualifying teams met at the Caterpillar Testing Facility in Peoria, IL in August 2017 for competition focused on the core 3D-Printing fabrication technologies and materials properties needed to manufacture structural components from indigenous materials combined with recyclables, or indigenous materials alone. Prize money totaling $701,000 was awarded. In November 2017, the 3D Printed Habitat Challenge entered Phase 3 with a prize purse of $2 million where habitats will be fabricated using autonomous additive manufacturing technology.
- Vascular Tissue Challenge - The purpose of the challenge is to produce viable thick-tissue assays that can be used to advance research both on earth and in space environments. The challenge opened in June 2016 and awards will be made to the first three teams to achieve the goals within a three-year timeframe. Eleven teams have signed up for the competition.

Technology Transfer and Partnerships

Technology Transfer provides Agency-level management and oversight of NASA-developed and NASA-owned intellectual property, and manages transfer of these technologies to external entities. Activities include active collection and assessment of all NASA inventions, strategic management and marketing of intellectual property, negotiation and management of licenses, software release, development of technology transfer-focused partnerships, and the tracking and reporting of metrics related to these activities (i.e., numbers of new inventions, patents, licenses, cooperative research and development agreements, and software use agreements). Several specific initiatives of NASA's Technology Transfer Program launched this year include:

- ATLAS: NASA launched its Automated Technology Licensing Application System (ATLAS), which allows high-tech entrepreneurs to apply for NASA patent licenses online using a simple, intuitive guided process. This new initiative is yet another step in NASA's process of modernizing and streamlining its technology commercialization efforts, making it simpler and faster for companies to find and use NASA technologies
- E-NTR: NASA has made reporting new inventions (New Technology Reports) easier than ever before with the launch of e-NTR system. The new system has standardized and streamlined the agency's invention disclosure process, reducing to a third the number of questions asked. The system is entirely online and accessible from anywhere.
- Software Catalog Release: NASA released its third Software Catalog in 2017. First launched in 2013, this is a comprehensive inventory of the modern software tools NASA has created in the course of its work, to make available to industry, academia and other government agencies.

EARLY STAGE INNOVATION AND PARTNERSHIPS

Agency Technology and Innovation

Agency Technology and Innovation funds the operations of the Office of the Chief Technologist and Agency activities for promoting innovative culture and partnerships within and outside of NASA, including with industry and commercial partners.

The NASA Chief Technologist serves as the Agency's principal advisor and advocate on matters concerning Agency-wide technology policy and programs to internal and external stakeholders. The office also communicates and helps strategically integrate technology efforts within the Agency. The office conducts an annual review and assessment of technology investments across NASA, including the mission-focused investments made by the Agency's mission directorates, performing strategic technology integration. The organization also assesses and communicates the societal and economic impact of technology investments at NASA and outside the Agency.

For example, the Office of the Chief Technologist held several Technical Interchange Meetings in support of NASA's participation in the interagency Science and Technology Partnership Forum activity, including topics such as In Space Assembly and Cybersecurity. The exchanges with the Department of Defense, the intelligence community, and other federal agencies shared progress on these topics of mutual interest. These exchanges are working to leverage synergies and influence portfolios through partnerships that reduce duplication of effort and investment across government, while advancing the technology readiness levels of technology applications that will benefit Agency missions. This innovative interagency collaboration combines the expertise, experiences and perspectives of the national space technology development community and leverages sharing of resources. The activity has created new opportunities for advancing technology while reducing costs to the taxpayer.

The Office of the Chief Technologist is also working on developing a new Technology Strategic Integration Framework, to more efficiently identify and connect technology investments to needs in order to help NASA achieve its aeronautics, science, and human exploration missions, including future deep space exploration to destinations such as the moon, Europa and Mars and strengthen the US industrial base. This effort will better inform future versions of the Space Technology Implementation Plan and technology roadmaps.

In addition, the Office of the Chief Technologist is the Agency champion for promoting a culture of innovation at NASA, particularly in regard to workforce development. The office identifies innovative technology partnerships and initiates collaboration to reduce costs and increase the return on investment through innovative partnerships. The office also serves as the NASA lead for the interagency Science and Technology Partnership Forum, an ongoing activity that brings leaders in government aerospace, defense, and national security communities together to better coordinate federal investments and activities based on mutual critical needs and future plans. For more information about the Office of the Chief Technologist, go to: http://www.nasa.gov/oct.

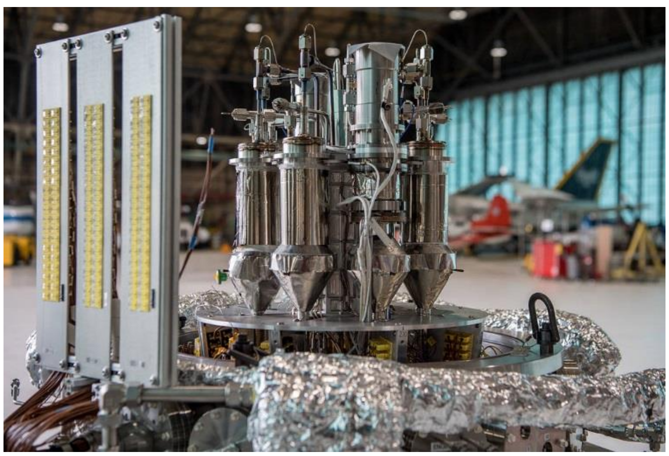
TECHNOLOGY MATURATION

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**135.0**	**--**	**216.5**	**178.6**	**180.8**	**183.3**	**183.5**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



The Kilopower prototype power system was designed and developed by NASA's Glenn Research Center in collaboration with NASA's Marshall Space Flight Center and the Los Alamos National Laboratory, while the reactor core was provided by the Y12 National Security Complex. The team at the National Security Complex connected the power system to the core and began end-to-end checkouts at the end of January 2018. A full-power test will be conducted in late March 2018. If successful, the system could provide abundant energy anywhere humans or robots travel including the shadowed craters of the moon, or manage power through the dust storms on Mars.

NASA is advancing disruptive space technologies from proof of concept to demonstration, maturing transformational and foundational technologies that primarily reside between early stage research and flight demonstration. Development of new technologies and capabilities lays the groundwork that enhances and enables space exploration beyond low earth orbit.

Exploration Research and Technology integrates the programmatic technology development content previously funded by Space Technology and Advanced Exploration Systems, and refocuses these activities toward Deep Space Exploration. In addition, Technology Maturation investments will support the Science Mission Directorate on exploration-related technology and research that also have relevance to achieving science goals.

In order to maintain a broad and diverse range of solutions for NASA's toughest challenges, the Technology Maturation portfolio utilizes the NASA workforce, commercial industry, and academia to develop and test prototype systems that will form the basis for meeting exploration mission requirements. Through public-private partnerships, NASA matures technologies to advance the emerging space economy while developing capabilities for NASA's exploration missions.

The Technology Maturation portfolio is organized to support the following exploration focus areas:

- Advanced environmental control and life support systems & in-situ resource utilization (ISRU);
- Power and propulsion technology (including space fission reactors, nuclear thermal propulsion, and high powered solar electric propulsion);

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- Advanced Materials;
- Communications, navigation and avionics (including laser communication, disruption tolerant networking and high performance spaceflight computing);
- Entry, descent and landing (including Lander technologies);
- Autonomous operations;
- In-space manufacturing and on-orbit assembly; and
- Research to enable humans to safely and effectively operate in various space environments.

EXPLANATION OF MAJOR CHANGES IN FY 2019

This program is restructured to align with NASA's Exploration Campaign and the associated technology areas of focus under the new Exploration Research & Technology (ER&T) organization. The content in the Technology Maturation portfolio consolidates projects funded previously within the Space Technology account, as well as content from Advanced Exploration Systems (AES), including Vehicle Systems and Foundational Systems, into a single account -- integrating and re-focusing these activities toward supporting Deep Space Exploration.

As FY 2018 and FY 2019 activities are phased out or otherwise concluded, this portfolio will increase its emphasis on technologies that benefit deep space exploration. For example, once the Station Explorer for X-ray Timing and Navigation Technology (SEXTANT) demonstration is completed, the Space Technology Mission Directorate (which will be part of the new Exploration Research & Technology organization) will discontinue Space System Observatory and Robotics technology development efforts under this program, but will continue to collaborate with the Science Mission Directorate to advance exploration science technologies where appropriate.

ACHIEVEMENTS IN FY 2017

- NASA awarded a contract to Boeing Co. for the development of the next generation, high performance spaceflight computer processors that will allow for flexible operations, lower power computers for space operations with 75x-improved performance over the state of the art RAD750.
- NASA selected Johns Hopkins/APL and Orbital ATK to advance the photovoltaic technologies in support of he Extreme Environment Solar Power project, which will provide reliable power for deep space missions, including those in the general vicinity of Jupiter.
- Commissioned and transitioned the SEXTANT demonstration to Science Operations Mode as part of the Neutron Start Interior Composition Explorer (NICER) science experiment on the International Space Station.
- Completed sounding rocket flight testing of carbon nanotube reinforced Composite Overwrapped Pressure Vessel to assess its durability during launch.
- Installed the Conformal Ablative Thermal Protection System on a small probe flight article provided by Terminal Velocity Aerospace (TVA), and launched on Orbital ATK’s commercial resupply services mission to conduct an orbital entry test of the conformal ablator heat shield material.
- Down-selected the fuel and reactor design for nuclear thermal propulsion as part of risk mitigation activities to establish a safe and affordable propulsion system that will enable faster trip times.

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- Three companies conducted initial ground tests of high-power (> 100 kW) electric thrusters as part of ongoing work under Next Space Technologies for Exploration Partnerships (NextSTEP) Phase 1 to enable next generation in-space propulsion systems. Those companies completed their year one milestones to assemble subsystems and upgrade test facilities.
- NASA demonstrated on-demand manufacturing, recycling, and sanitizing of a urine funnel by demonstrating a Refabricator that will recycle plastic parts to produce feedstock for an integrated 3D printer. In-space manufacturing can greatly reduce the inventory of spare parts and tools that are needed on long missions. A Broad Agency Announcement was also released to solicit proposals for a multi-material fabrication laboratory (FabLab) which is a small-scale workshop offering advanced in-space fabrication.

WORK IN PROGRESS IN FY 2018

- Complete the full power test of the 1kW kilopower fission reactor at the Nevada National Security Site. This technology will aid in the future design of a modular 10kW-class system that would provide abundant energy for surface exploration.
- Complete detailed design of all components and subsystems for the Mars Entry, Descent and Landing Instrumentation (MEDLI2) and Mars Environmental Dynamics Analyzer (MEDA) technology instrument projects.
- Refine the nuclear thermal propulsion fuel element and reactor conceptual design to include reactor general design, performance analysis, mechanical design, core fabrication development, and fuel fabrication development.
- Complete the Engineering Test Unit (ETU) for the Heatshield for Extreme Entry Environment Technology (HEEET) project to support exploration and science missions to extreme environments.
- Complete life testing of Bulk Metallic Glass Planetary Gears and Strain Wave Gears to enable more robust mobility systems for future extreme environment exploration and science missions.
- Using Advanced Near Net Shape Technology, a novel metal forming technique to manufacture integrally stiffened aerospace structures, NASA will complete charaterization of a 10-ft. diameter integrally stiffened cylinder. The resulting product is 50 percent lower cost and 10 percent lighter weight than traditionally machined and welded parts due to fewer welds and minimized machining requirements.
- Continue to develop advanced in-space propulsion, landing capabilities, in situ resource utilization and overall capabilities to support future human spaceflight missions. NASA plans to conduct vacuum chamber tests of high-power electric propulsion systems operating for 100 continuous hours under the NextSTEP-1 awards.
- In an effort that reduce logistic requirements and improve operational flexibility, NASA will continue to maintain investments in in-space manufacturing technology development and demonstration on ISS. NextSTEP BAA contracts will be awarded to develop a multi-material fabrication laboratory (FabLab) that will be demonstrated on ISS.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

Starting in FY 2019, NASA prioritizes its investments to maximize alignment with the new Exploration Campaign with an emphasis on: advanced environmental control and life support systems & ISRU; power and propulsion technology (including space fission reactors, nuclear thermal propulsion, and high powered Solar Electric Propulsion); advanced materials; communications, navigation and avionics technology (including laser communications, disruption tolerant networking and high performance spaceflight computing); entry, descent and landing (including lander technologies); and autonomous operations.

- In the area of advanced environmental control and life support systems and ISRU, NASA will deliver oxygen recovery brassboards capable of at least 75 percent oxygen recovery from carbon dioxide. NASA will also deliver a NASA-sponsored instrument for the Korean Aerospace Research Institute (KARI) lunar mission, Korea Pathfinder Lunar Orbiter (KPLO). This instrument, ShadowCam, will capture low-light images of the Moon's permanently shadowed regions to search for evidence of frost or ice deposits.
- In the area of power and propulsion, NASA will complete integrated xenon system testing within the sub-kilowatt electric propulsion project, and prototype a detailed design review for Extreme Environments Solar Power,
- In the area of communications, avioncs and navigation, NASA will conduct a critical design review planned for high performance spaceflight computing, and initiate Advanced Memory project in partnership with the Air Force Research Laboratory to target volatile and non-volatile memory devices to support processor and digital devices.
- In the area of advanced materials, NASA will conduct a flat floor functional deployment test for Deployable Composite Boom project that focus on maturing deployable composite boom technology for small volume, CubeSat/EELV Secondary Payload Adapter (ESPA) class satellite deployable systems. In addition, NASA will complete testing of longitudinal and circumferential joints for the Composite Technology for Exploration project. This project develops and demonstrates critical composites technologies, specifically bonded joint technology for Space Launch System scale composite hardware. In addition, Rapid Analysis Manufacturing Propulsion Technologies will complete hot fire test and material testing and subscale Phase I testing.
- NASA will complete hardware build and deliver the MEDLI-2 and Mars Environmental Dynamics Analyzer for launch on the Science Mission Directorate (SMD) Mars 2020 mission. MEDLI-2 technology instrument will acquire data that will enable improved designs of future Mars entry systems for robotic and crewed missions, while MEDA will measure Mars weather conditions.

Program Elements

NASA will execute a technology portfolio that enables human exploration across the solar system, and bring new knowledge and opportunities back to Earth enabled by the high priority technology focus areas described in further detail below. Within these activites, NASA will utilize public-private partnerships where advantageous. These agreements enable NASA and private sector industry to share in the risk and benefit of government investments. These shared risks and benefits include incentivizing technical performance, the building of future commercial markets, and a shared financial interest in the development of capabilities.

SPACE POWER AND PROPULSION

NASA is making critical advancements in power generation and energy storage technologies for science and human exploration missions. Propulsion investments focus on higher thrust and efficiency, including alternatives to traditional chemical propulsion systems for deep space exploration spacecraft systems.

TECHNOLOGY MATURATION

Specific investments include development of solar array technology that can generate energy in extreme environments including low light intensity and low temperature; development and testing of a scalable 1kW surface fission power generation system; and rapid transit nuclear thermal propulsion technology utilizing low-enriched uranium that could potentially provide 20 percent shorter travel time to Mars while substantially improving mission flexibility. Key projects that support this thrust area include the following:

- Kilopower: Through a partnership with Department of Energy's National Nuclear Security Administration and Los Alamos National Lab, and small businesses Sunpower, Inc and Advanced Cooling Technologies, NASA is developing a 1kW prototype of a fission power subsystem that is scalable and will potentially provide surface power capability for space exploration. The Kilopower assembly went through vacuum testing at Glenn Research Center for thermal cycling checkout, and will conduct full power test in early FY 2018 at the Nevada National Security Site. If successful, NASA will advance this effort to a flight demonstration, and ultimately a 10 kW system for surface power.
- Nuclear Thermal Propulsion (NTP): Investments will enable more efficient spaceflight by developing improved fuel element sources to support potential future nuclear thermal propulsion efforts. In FY 2018, the nuclear thermal propulsion project will continue to refine the NTP technology maturation and ground demonstration plan; complete assessment of a NTP Mars transportation architecture; continue feasibility analysis based on cermet fuel element/reactor conceptual design; update and deliver a final Low-Enriched-Uranium (LEU)-based nuclear thermal propulsion system cost analysis; and refine the fuel element reactor conceptual design. Industry and government involvement include Aerojet Rocketdyne, AMA, Aerospace, BWXT, and Department of Energy. Risk mitigation activities will complete in FY 2019, culminating in a concept review and determination of whether to proceed with a ground demonstration phase.
- Sub Kilowatt Electric Propulsion: NASA will demonstrate a ~0.5 kW Hall electric propulsion thruster to be used on ESPA class spacecraft that support exploration and science missions. Recent advances in Hall thruster technology at the 13-kW power level can be applied to 0.5 kW device to drastically alter the spacecraft market with low development risk. The project plans to deliver an engineering qualification model thruster and PPU design in FY 2019 and eventually complete an integrated (xenon and iodine) thruster testing.
- 600W Hall Thruster Qualification Life Test: Through an Announcement of Collaborative Opportunity (ACO) in FY 2018, NASA awarded Busek a three-year project to perform life testing of the BHT-600 Hall Effect Thruster and BHC-1500 Hollow Cathode Assembly (HCA) coupled to a Power Processing Unit. This technology could be infused into sub-KW power level Electric Propulsion systems.
- Modular Power Systems will demonstrate a modular power architecture composed of technologies for power generation, energy storage, power distribution and health management that will reduce the cost of future space systems.
- Other ongoing initiatives include work on advanced propulsion under the NextSTEP BAA awards and modular power for multiple exploration vehicles and systems such as fuel cells.

ADVANCED COMMUNICATIONS, NAVIGATION AND AVIONICS

NASA will fundamentally transform spacecraft systems through investment in high payoff technologies that increase communication data rate and advance deep space navigation and flight avionics. Key projects within this portfolio include the following:

TECHNOLOGY MATURATION

- High Performance Spaceflight Computing: With the Air Force Research Laboratory, NASA is developing a next generation high performance space flight computing system that will lead to vastly improved in-space computing performance, energy management, and increased radiation fault tolerance. The new radiation tolerant microprocessor will offer a 75 times improvement in performance relative to the current state of the art RAD750 processor while requiring the same power.
- Software Defined Reliability for Mission Critical Operations: through an FY 2018 ACO, awarded to Astrobotic Technology, this two-year project will mature Astrobotic's software-defined reliability system for computing.
- Communicating from Earth to any spacecraft is a complex challenge, largely due to the extreme distances involved. When data are transmitted and received across thousands and even millions of miles, the delay and potential for disruption or data loss is significant. Delay/Disruption Tolerant Networking (DTN) is NASA's solution to reliable internet working for space missions.
- Ka-Band Objects Observation and Monitoring (KaBOOM) will use three 12-meter diameter antennas at NASA's Kennedy Space Center (KSC) to demonstrate a Ka-Band phased array of widely separated antennas that can instantly compensate for atmospheric twinkling to improve what is seen.

ADVANCED MATERIALS

NASA supports innovation in materials development and low-cost manufacturing that enables increased mission cargo capacity by reduction of structural mass. NASA looks for opportunities to improve the manufacturing technologies, processes, and products prevalent in the aerospace industry. NASA's unique needs enable a network of collaboration and partnerships with industry, academia, and other government agencies to accelerate innovative manufacturing methods and technologies. Key projects within this portfolio include the following:

- Advanced Near Net Shape Technology: This technology uses innovative metal forming techniques to manufacture integrally stiffened aerospace structures such as cryotanks. The resulting product is 50 percent lower cost and 10 percent lighter due to fewer welds and minimized machining. NASA will build on previous prototyping efforts focusing on scaling up the process for commercial launch vehicles. Industry partners include MT Aerospace, Lockheed Martin, and Leifeld Metal Spinning, in Ahlen, Germany.
- Additive Construction for Mobile Emplacement: will develop full-scale hardware to 3D print infrastructure components using analog planetary in-situ materials, while developing full-scale hardware with the United States Army Corps of Engineers for terrestrial applications.
- Bulk Metallic Glass: Bulk Metallic Glass gears improve rover mobility performance at low temperatures by eliminating the need for gear lubricant and associated heaters. This project will deliver planetary gears and strain wave gears that will enable planetary surface missions where temperatures drop below the freezing point of typical lubricants.
- Composite Technology for Exploration: By developing new analytical methods to design, build and test innovative hardware, NASA looks to enable a significant increase in the use of new composite materials for the next generation of rockets and spacecraft needed for space exploration.
- The Rapid Analysis Manufacturing Propulsion Technology (RAMPT) project will develop and advance large-scale light weight manufacturing techniques and analysis capabilities required to reduce design and fabrication cycles for regenerative-cooled liquid rocket engine components.

TECHNOLOGY MATURATION

RAMPT impacts all phases of the thrust chamber life cycle by reducing design, fabrication, assembly schedules (60%) and allowing for reduced parts, increased reliability, and significant weight reduction (70%). RAMPT will partner with industry through a public-private partnership to design and manufacture component parts of the thrust chamber.

- Deployable Composite Boom: The objective of this project is to mature deployable composite boom technology for use in low-cost, small volume, CubeSat/ESPA class spacecraft deployable systems. A technology gap has been identified for deployable composite booms that are 5-20m long and capable of packing into a 0.5-3 U volume. These types of booms enable high power solar arrays, antennas for high data rate communications, and high Delta-V propulsion systems to be included on small CubeSat/ESPA class spacecraft.
- In an effort to provide efficient mission and ground operations with reduced dependence on Earth resource, NASA is continuing to invest in in-space manufacturing technologies, including the development of the FabLab for ISS.

ADVANCED ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS AND IN SITU RESOURCE UTILIZATION

NASA will fundamentally transform spacecraft systems through investment in high payoff technologies that advance atmospheric capture and conversion aspects of in-situ resource utilization technologies, closed-loop life support systems, and develop capabilities to mitigate space radiation. Key projects within this portfolio include the following:

- Advanced Radiation Protection: Insufficient data exists to validate thick shield space radiation exposure predictions. The Advanced Radiation Protection project will validate the shielding efficiency of spacecraft materials and verify an optimum Galactic Cosmic Ray shield thickness needed for minimal mass vehicle design. To this end, the project team will work with the NASA Space Radiation Laboratory to design and build radiation detector stands and targets to support a testing of various materials (aluminum, polyethylene, combination). This effort will result in data that will inform deep space habitat construction. This project can be viewed as the necessary first step in the development of a vehicle optimization capability for long duration, heavily shielded vehicles.
- Spacecraft Oxygen Recovery: Oxygen recovery systems are critical when oxygen resupply from Earth is not available, and will be enabling for long-duration human missions. NASA awarded two contracts, Honeywell Aerospace and UMQUA Research Co., to develop technologies that will increase the oxygen recovery rate aboard human spacecraft to at least 75 percent while achieving high reliability. Future maturation of these technologies may be used by the ISS as a proving ground to retire risk and gain experience with capabilities needed for deep-space exploration.
- The Korea Pathfinder Lunar Orbiter (KPLO) spacecraft will carry a total of five instruments to lunar orbit—four from South Korea and one from NASA (developed by Arizona State University and Malin Space Science Systems). ShadowCam, the US provided instrument, will map the reflectance within the permanently shadowed regions to search for evidence of frost or ice deposits. The instrument's optical camera is based on the Lunar Reconnaissance Orbiter Narrow Angle Camera, but is 800 times more sensitive, allowing it to obtain high-resolution, high signal-to-noise imaging of the moon's permanently shadowed regions. ShadowCam will observe these regions monthly to detect seasonal changes and measure the terrain inside the craters, including the distribution of boulders. ShadowCam will address strategic knowledge gaps, or lack of

information required to reduce risk, increase effectiveness, and improve the designs of future human and robotic missions.

~~COMMUNICATIONS~~AUTONOMOUS SYSTEMS

Autonomous systems are critical when exploring or operating in an extreme environment, on Earth or in space (especially for outer planets exploration). This portfolio supports technologies that benefit space exploration and also support manufacturers, businesses and other entities. Key technology efforts include:

- Autonomous Medical Operations: The objective of this project is to develop a "medical decision support system" to enable astronauts on long-duration exploration missions to operate autonomously while independent of Earth contact. Such a system is not intended to replace a "Chief Medical Officer" (CMO), but rather to support the CMO's medical actions by providing advice and procedure recommendations during emergent care and clinical work. The Autonomous Medical Operations system will enable rapid, assured acquisition and analysis of sensor data to support differential diagnosis; analysis from medical on-board notes and on-board databases (including tailoring to individual astronauts); and automated reasoning using structured and unstructured data.
- Autonomous Pop Up Flat Folding Exploration Robot: The objective of this project is to enable the "Pop-Up Flat Folding Explorer Robots" (PUFFER) to operate autonomously, both individually and as a multi-robot team. PUFFER is a miniature mobile robot that is designed as a low-volume, low mass, low-cost mission enhancement for accessing new high interest extreme terrains. PUFFER is capable of supportingfuture lunar, Mars and icy moon missions, as well as extreme terrains on Earth.

ENTRY, DESCENT AND LANDING (EDL) SYSTEMS

In order for NASA to land more mass, more accurately on planetary bodies, as well as improve capabilities to return spacecraft from low Earth orbit and deep space, the Agency must develop more capable entry, descent, and landing systems, materials, and modeling capabilities. NASA invests in technologies focused on the design, analysis, and testing of advanced materials for thermal protection and aeroshell architectures required for future exploration vehicles and planetary entry missions. Key projects within the Entry, Descent and Landing Systems include:

- Safe and Precised Landing Integrated Capabilities Evolution (SPLICE), a precision landing and hazard avoidance technology, will be infused into future robotic science missions. The project will strive to tie entry uncertainty to a safe & precise landing. By the end of the project, the goal is to reach 200m/s with Line of Sight Velocity and greater than 4 km in Line of Sight Range.
- Heat Shield for Extreme Entry Environment Technology (HEEET) is an advanced thermal protection system that consists of a high-density all-carbon surface layer below which is a lower density layer composed of a blended carbon phenolic yarn which is then infused with a mid-density level of phenolic resin. The mass efficiency of HEEET permits exploration and science missions to target much lower entry g-load compared to current state-of-the-art.
- NASA will emphasize technologies to enhance lander technology and improve autonomous precision landing with hazard avoidance on lunar and planetary surfaces. NASA shares these landing capabilities through public-private partnerships with industry through multiple partnership and contract mechanisms.

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- Mars 2020 Entry, Descent and Landing Instrumentation: HEOMD, SMD, and STMD (which will be part of the new Exploration Research & Technology organization) are collaborating to develop the second-generation sensor suite for incorporation into the mission heat shield. This effort will further improve our understanding of entry system performance by acquiring flight data from an actual Mars mission, informing NASA designs for future exploration missions.

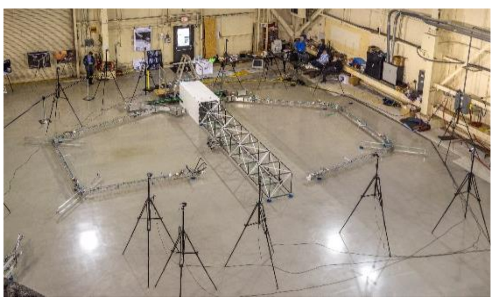
TECHNOLOGY DEMONSTRATION

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Laser Comm Relay Demo (LCRD)	25.7	21.5	**17.2**	0.0	0.0	0.0	0.0
Restore/In-Space Robotic Servicing (ISRS)	130.0	--	**45.3**	45.3	45.3	45.3	45.3
Solar Electric Propulsion (SEP)	23.4	--	**48.1**	24.6	18.4	4.9	0.0
Small Spacecraft, Flight Opportunities & Other Tech Demonstration	83.6	--	**222.2**	223.2	223.2	234.2	238.9
Total Budget	**262.8**	**--**	**332.7**	**293.1**	**286.9**	**284.4**	**284.2**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



Innovative NASA robotic technologies such as TALISMAN, seen here during calibration tests at NASA's Langley Research Center, are critical to the CIRAS project, which seeks to enable space-based, robotic assembly of flight hardware and space systems. This is one of three concepts being developed.

The Technology Demonstration portfolio conducts both ground-based testing to determine feasibility, and space flight demonstrations to transition new capabilities, to NASA exploration missions, and potentially to other government agencies and industry.

Current and future projects in this portfolio are being aligned to NASA’s new Exploration Campaign technology areas of focus, with an emphasis on the near-term lunar exploration goals. The areas of technology focus include: power and propulsion technologies, including cryogenic fluid management and solar electric propulsion; advanced communications and navigation demonstrations; in-situ resource utilization; entry, descent and landing; and in-space manufacturing and on-orbit assembly technologies.

While these technologies primarily benefit space exploration, several of these technologies offer the potential for commercial benefits, as well. Where this potential is high, public-private partnerships will be used to enable NASA to share the risk and financial interest with private sector industry and better leverage government investments. For example, in-space manufacturing and assembly offers a broad range of potential benefits while entry, descent and landing technologies required for exploration could provide the capability to return large payloads to Earth enabling the re-use of space systems and potentially the affordable return to Earth of objects manufactured in space.

This account also supports platforms that enable technology demonstrations in relevant environments through Flight Opportunities suborbital flights and to demonstrate capabilities and acquire strategic knowledge through Small Spacecraft platforms (including Cubesats) and the Cubesat Launch Initiative.

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Examples include using vertical takeoff, vertical landing rockets to demonstrate precision landing and hazard avoidance software and avionics, and using CubeSat robotic precursor activities to acquire strategic knowledge about potential destinations for human exploration such as prospecting for lunar ice.

EXPLANATION OF MAJOR CHANGES IN FY 2019

The Technology Demonstration program is restructured and consolidated to align with NASA's Exploration Campaign and the associated technology areas of focus. The content consolidates projects previously funded under the Space Technology account (including Technology Demonstration Missions, Flight Opportunities, and Small Spacecraft Technology), and from the Human Exploration and Operations Mission Directorate (HEOMD) Advanced Exploration Systems (AES) Robotic Precursor Domain. This consolidation creates a single portfolio, integrating and re-focusing these activities toward supporting Deep Space Exploration. As FY 2018 and FY 2019 activities are phased out or otherwise concluded, this portfolio will invest resources in technologies that benefit deep space exploration.

ACHIEVEMENTS IN FY 2017

- Solar Electric Propulsion completed a Preliminary Design Review under the Advanced Electric Propulsion Subsystem contract with Aerojet Rocketdyne. This electrically propelled propulsion system will use 10 times less propellant than a comparable, conventional chemical propulsion system, and can provide enough force over a period of time to move cargo and perform orbital transfers.
- In-Space Robotic Manufacturing and Assembly completed its first year of design, development, and ground testing with three contractors - Made-In-Space, Inc, Orbital ATK, and Space Systems Loral. NASA and its commercial partners are developing methods to manufacture, assemble and repair large structures in space.
- The Restore-L project awarded the spacecraft bus contract to Space Systems Loral and completed a System Requirements Review and passed Key Decision Points A and B.
- Seventeen technology payloads were flown across eight Flight Opportunities campaigns: three parabolic, three high-altitude balloon and two low-altitude rocket-powered entry, descent and landing tests. This included a laser-guided navigation sensor that could help future landers and rovers make safe, precise landings on the moon, Mars or destinations beyond was tested in April 2017 in California's Mojave Desert. The Navigation Doppler Lidar and Lander Vision System were flight tested aboard Masten Space Systems' rocket-powered Vertical Take-off, Vertical Landing (VTVL) platform.
- Selected experiments to fly on the Materials International Space Station Experiments (MISSE) to the ISS beginning in FY 2018 include six material samples for MISSE-09, four experiments for MISSE-10 and five for MISSE-11. The harsh environment of low-Earth orbit exposes the materials to a vacuum, atomic oxygen, ultraviolet radiation, direct sunlight and extreme heat and cold. The experiments provide a better understanding of material durability, from coatings to electronic sensors, which could be applied to future spacecraft designs.
- Through HEOMD/AES NextSTEP Phase 1 activities, three small satellites called Cubesats were selected to fly on Exploration Mission 1 (EM-1); the first planned flight of the Space Launch System (SLS) and the Orion spacecraft.
- The Jet Propulsion Laboratory completed testing of the Deep Space Atomic Clock and successfully integrated and tested the flight unit onto the Orbital Test Bed Spacecraft.

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- The Evolvable Cyrogenics (eCryo) project made its final delivery of the Radio Frequency Mass Gauge to the Goddard Space Flight Center for integration with the Robotic Refueling Mission #3.

WORK IN PROGRESS IN FY 2018

- Two small spacecraft missions were successfully launched on November 12, 2017 from NASA's Wallops Flight Facility aboard Orbital ATK's Cygnus spacecraft. The Integrated Solar Array and Reflect Antenna mission will demonstrate enhanced radio communications, and the two Optical Communications and Sensory Demonstration spacecraft will test optical laser communications and formation flight. The CubeSat Proximity Operations Demonstration will demonstrate rendezvous and docking capabilities for small spacecraft in late 2018.
- NASA will launch two payloads aboard the U.S. Air Force's Space Test Program-2 Launch, the Deep Space Atomic Clock, which will demonstrate precision navigation for six months; and the Green Propellant Infusion Mission, which will have a one year mission to prove the performance of this low-toxicity monopropellant alternative to hydrazine.
- As part of ongoing work under the NextSTEP-1 awards, NASA plans to conduct vacuum chamber tests of high-power electric propulsion systems operating for 100 continuous hours.
- NASA will maintain investments in efforts that reduce logistics requirements, including in-space manufacturing technology development and demonstration on ISS. NextSTEP BAA contracts will be awarded to develop a multi-material fabrication laboratory (FabLab) that will be demonstrated on ISS.
- eCryo will continue to prepare for the test of the Structural Heat Intercept Integration Vibration Evaluation Rig (SHIIVER) tank to be conducted at the Glenn Research Center Plum Brook Station. The tank will be used to demonstrate advanced insulation blankets, foam insulation and vapor-based cooling that are needed to help maintain very cold liquid propellants to be used as fuel for deep space missions.
- The Deep Space Optical Communications (DSOC) project will complete its Preliminary Design Review and Key Decision Point-C to align with the Science Mission Directorate Psyche mission schedule. This system will be capable of delivering information rates at least 10 times faster than conventional systems that use comparable mass and power.
- The three In-Space Robotic Manufacturing and Assembly contractors will complete the ground based development and testing phase and prepare for a potential follow-on flight demonstration.
- The Restore-L project held a Preliminary Design Review in early FY 2018 while continuing to make steady progress on robotics, propellant transfer, avionics, and rendezvous and proximity operations subsystem technologies. An Industry Day was held to help enable transfer of the critical satellite servicing technologies to aid the nascent commercial satellite servicing industry.
- UP Aerospace SpaceLoft-12, to be flown in late FY 2018 from Spaceport America in New Mexico, will test both the Adaptable Deployable Entry and Placement Technology (ADEPT) and Affordable Vehicle Avionics (AVA) technologies under development at the Ames Research Center.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

Starting in FY 2019, NASA is prioritizing its investments to maximize alignment with the new Exploration Campaign objectives with an emphasis on: advanced environmental control and life support systems & ISRU; power and propulsion technology (including space fission reactors, nuclear thermal propulsion, and high powered Solar Electric Propulsion); advanced materials; communications, navigation and avionics technology (including laser communications, disruption tolerant networking and high performance spaceflight computing); entry, descent and landing (including lander technologies); and autonomous operations.

- In the area of advanced communications technologies, NASA will complete and launch the Laser Communications Relay Demonstration (LCRD) in mid-2019. LCRD is the next step in implementing NASA's vision of using optical communications for both near-Earth and deep space missions, which will help NASA understand the best ways to operate laser communications systems and enable much higher data rates for connections between spacecraft and Earth, such as scientific data downlink and astronaut communications. In addition, the Deep Space Optical Communications project will conduct its Critical Design Review.
- The Solar Electric Propulsion Project will complete the Critical Design Review for the electric propulsion subsystem, conduct ground testing of the Solar Electric Propulsion engineering development units for the high power, magnetically-shielded Hall effect thrusters and begin fabrication of the flight qualification hardware to support a space demonstration.
- Upon completion of the ground demonstration of the public-private partnership on the In-Space Robotic Manufacturing and Assembly projects, NASA will enter into a formulation phase to flight demonstrate the technology capabilities needed to build large structures in space.
- MOXIE and Terrain Relative Navigation will deliver their payloads for integration and testing with the rover for launch on the Mars 2020 Mission.

Program Elements

POWER AND PROPULSION

Advanced ROSA solar array demonstration on ISS, July 2017

Solar Electric Propulsion:

The Glenn Research Center (GRC) will continue development of Solar Electric Propulsion with higher-power, longer-life thrusters and power processing units. The use of electric thrusters on commercial satellites continues to increase, and previous NASA advancements in deployable solar array structures, with half of the mass and one-third of the packaging volume compared to the best current arrays, are already being incorporated into commercial satellite product lines.

GRC successfully developed and tested technology demonstration units for Hall-effect thrusters operating at approximately 13 kilowatts and with magnetic shielding to permit years of continuous operations without degradation. A three-year contract for engineering and qualification unit delivery of thrusters and power processing units was awarded in Spring 2016 to Aerojet Rocketdyne, Inc. In FY 2018, NASA will begin ground testing of the engineering development units for the thrusters and begin fabrication of the qualification units in FY 2019. Once proven, high-powered Solar Electric Propulsion can efficiently propel more ambitious, robotic science and human exploration missions beyond the Earth and into deep space. Furthermore, Solar Electric Propulsion will enable more efficient orbit transfer of spacecraft and accommodate the increasing power demands for government and commercial satellites.

Evolvable Cryogenics/Cryogenic Fluid Management

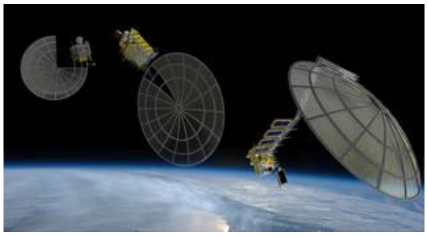
The Evolvable Cryogenics project is conducting a series of ground demonstrations at Marshall Space Flight Center (MSFC) and GRC to validate the performance of propellant storage tanks designed for long-term on-orbit storage. In addition to managing the propellant boil-off by validating the effectiveness of advanced multi-layer insulation, the team is evaluating the reduction of ancillary system mass and complexity. The project will also investigate the utilization of remaining boil-off gases to replace existing pressurization and attitude control systems, and to provide electrical power for the Space Launch System (SLS) Exploration Upper Stage and other launch vehicle systems. The team is also developing new cryogenic monitoring instrumentation and analytical models to assist in determining cryogenic system health during in space operations. For NASA, these technologies enable beyond low-Earth orbit exploration missions, while industry will likely infuse the technologies on next generation launch vehicles and on-orbit stages, making them more efficient and capable. By taking an incremental ground test approach, NASA is prioritizing technologies needed by Exploration, including SLS upper stage development, and the long-term needs of the aerospace industry as a whole. The project will build on the knowledge gained from previous investments and utilize existing Agency assets and test facilities capable of maturing cryogenic propellant transfer and storage technologies. NASA intends to initiate a Cryogenic Fluid Management (CFM) flight demonstration phase, using the results of an internal NASA CFM road-mapping activity, a 2017 Cryogenic Fluid Management Request for Information, and direct discussions with industry partners to formulate the technology demonstration priorities and acquisition approach.

Green Propellant Infusion Mission

Green Propellant Infusion Mission is a dedicated spacecraft to demonstrate non-toxic propellant propulsion with the goal to provide an alternate to hydrazine propellant applicable to a small to medium-sized spacecraft. Higher performing and safer propellant alternatives are at a tipping point. Once demonstrated in-space, rapid incorporation could occur into a variety of spacecraft. NASA selected AF-M315E as an innovative, low-toxicity monopropellant alternative with improved performance over hydrazine. The AF-M315E propulsion system is expected to improve overall vehicle performance by 40 percent and processing efficiency while decreasing operational costs by reducing health and environmental hazards. The green propellant formula, thrusters, and related systems will perform a series of in-space demonstration tests. NASA has secured a rideshare opportunity for technology demonstration through the STP-2 launch of a SpaceX Falcon Heavy, which is scheduled to launch in mid-2018. In addition, the Space Technology Mission Directorate (which will be a part of the new Exploration Research & Technology) continues to work with Aerojet Rocketdyne to revise the one-Newton thruster design to implement improvements to better enable commercial infusion potential following the in-space demonstration, through a public-private partnership collaboration.

TECHNOLOGY DEMONSTRATION

ROBOTIC IN-SPACE MANUFACTURING AND ASSEMBLY OF SPACECRAFT AND SPACE STRUCTURES




These artist's renderings depict Archinaut (left) and Dragonfly (right) Archinaut uses additive manufacturing to produce new or replacement structures including lengthy beams and struts. Dragonfly enables satellite self-assembly in orbit.

In-Space Robotic Manufacturing and Assembly

In partnership with commercial industry, NASA develops and demonstrates technologies required to manufacture, assemble, and aggregate large and/or complex systems in space utilizing robotic and additive manufacturing technology. Presently, launch-shroud size, lift capacity, and launch loads/environments limit the size and capabilities of systems pre-assembled on the ground and deployed using a single launch. With advances in ultra-lightweight materials, additive manufacturing, robotics, and autonomy, in-space manufacturing, assembly, and aggregation concepts are now at a tipping point. The following competitively awarded proposals were selected in November 2015 to conduct ground development of robotic manufacturing and assembly technologies:

- Public-Private Partnership for Robotic In-Space Manufacturing and Assembly of Spacecraft and Space Structures—Orbital ATK of Dulles, VA;
- Versatile In-Space Robotic Precision Manufacturing and Assembly System—Made in Space, Inc. of Moffett Field, CA; and
- Dragonfly: On-Orbit Robotic Installation and Reconfiguration of Large Solid Radio Frequency (RF) Reflectors—Space Systems Loral of Palo Alto, CA.

All three are on track to complete ground demonstrations in ambient or thermal vacuum conditions by the end of FY 2018. This disruptive capability could transform the traditional spacecraft-manufacturing model by enabling in-space creation of large spacecraft systems. No longer will developing, building, and qualifying a spacecraft focus so heavily on an integrated system that must survive launch loads and environments. These crosscutting technologies could also greatly reduce cost while increasing capabilities for both NASA and commercial space applications. The FY 2019 budget request includes funding to conduct follow-on activities for an affordable flight demonstration of in-space manufacturing and robotic assembly technologies.

RESTORE-L/SATELLITE SERVICING

NASA will continue to restructure its investment in the development of satellite servicing technologies to reduce its overall cost. Public private partnerships will be further explored, as well as completion of the spacecraft bus contracted effort. This project will build off of the Restore-L preliminary design completed in FY 2018 and support technologies that will feed into NASA's needs for human exploration. The

TECHNOLOGY DEMONSTRATION

project will target technology development and subsequent flight demonstration of critical satellite servicing technologies of benefit to the nascent commercial satellite servicing industry.

ADVANCED ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS AND IN SITU RESOURCE UTILIZATION

Mars Oxygen In-Situ Resource Utilization (ISRU) Experiment (MOXIE)

The Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) will demonstrate in-situ resource utilization technologies to enable propellant and consumable oxygen production from the Martian atmosphere for future exploration missions. Specifically, MOXIE will produce oxygen from a Mars atmosphere, demonstrate the feasibility of ISRU on Mars, validate analytical models for scaling up of future ISRU systems, and provide valuable knowledge needed for future mission development. MOXIE will fly on the Science Mission Directorate's Mars 2020 mission.

ENTRY DESCENT AND LANDING

Terrain Relative Navigation

The Terrain Relative Navigation project will improve targeting accuracy for landing and provide hazard avoidance to enable access to scientifically compelling sites with acceptable risk. All of NASA's current human and robotic precursor mission architectures for planetary surface exploration require this technology. Using Terrain Relative Navigation, the Mars 2020 powered descent vehicle will estimate its location while descending through the Martian atmosphere. This allows the vehicle to determine its position relative to the ground with an accuracy of about 200 feet (60 meters) or less. Upon successful demonstration, this technology will provide capability to land near pre-deployed assets, provide the capability to avoid large scale landing hazards during entry, descent, and landing operations, and will reduce post-landing surface drive distances.

Low Earth Orbit Flight Test of Inflatable Decelerator (LOFTID)

NASA, in partnership with United Launch Alliance, will conduct a flight test of inflatable entry vehicle technology in the Earth's atmosphere to determine the feasibility of this technology in supporting high mass Entry Descent and Landing. This project will also demonstrate capabilities for a high mass return to Earth from Low Earth Orbit that could enable commercial applications such as flight hardware re-use and return of products manufactured in space for terrestrial use. The reentry vehicle will be flown as a secondary payload on a ULA Atlas V launch vehicle and used to deliver a primary payload to Earth orbit. After the primary payload is released, the Atlas V Centaur upper stage will orient and de-orbit the reentry vehicle for an Earth re-entry. The flight will test High Mass Entry Descent and Landing technology at a scale (6m) and at conditions relevant to identified Earth and Mars mission infusion opportunities. By conducting this effort with an industry cost-sharing partnership, NASA is significantly reducing the overall cost of this technology while enabling a potential commercial capability to achieve efficient, high mass return to Earth from Low Earth Orbit.

TECHNOLOGY DEMONSTRATION

Precision Landing

NASA will begin pre-formulation activities for a Precision Landing flight demonstration that includes the technologies to develop a capability which enables robotic and human missions to land safely in hazardous terrain, and/or in specified locations of scientific interest or near pre-deployed assets. Technologies for precision landing include low-Size, Weight, and Power optical, Light Detection and Ranging, and other sensors; guidance, navigation and control algorithms; and high-performance, real-time computational hardware and software.

COMMUNICATIONS, NAVIGATION AND AVIONICS

In addition to the projects below, the Laser Communications Relay Demonstration seeks to change the way we send and receive data, video and other information, using lasers to encode and transmit data at rates 10 to 100 times faster than today's fastest radio-frequency systems, using significantly less mass and power. This project in development is described further in a separate section that follows.

Deep Space Optical Communication

The Deep Space Optical Communications project led by the Jet Propulsion Laboratory (JPL) will develop key technologies for the demonstration of a deep space optical flight transceiver and ground receiver that will provide greater than 10 times the data rate of a state of the art deep space RF system (Ka-band). This capability will enable future advanced instruments, live high definition video, tele-presence, and deep-space human exploration of the solar system. Deep Space Optical Communication technologies are considered essential for future human missions to Mars and have a wide range of applications for planetary science missions including those to Mars and the Jovian systems.

NASA successfully completed and reduced significant risks on technologies including a low mass spacecraft disturbance isolation assembly, a flight qualified photon counting detector array, a high efficiency flight laser amplifier, and a high efficiency photon counting detector array for the ground-based receiver. Deep Space Optical Communication will demonstrate a high bandwidth flight laser optical communication terminal on the Science Mission Directorate's Psyche mission.

Deep Space Atomic Clock

The Deep Space Atomic Clock project led by JPL has the objective to validate a miniaturized, mercury-ion, atomic clock that is 100 times more accurate than today’s state of the art space clocks used for spacecraft navigation systems. To be launched in FY 2018, the Deep Space Atomic Clock will demonstrate ultra-precision timing in space and its benefits for one-way radio-based navigation. If successful, it will free up precious deep space communications bandwidth to perform greater scientific data return. The enhanced navigation and increased communications bandwidth permitted by the new clock will dramatically improve the exploration mission requirement for advanced communication capabilities. Precision timing and navigation provided by the new clock will also have the potential to improve the Nation’s next generation GPS system. The demonstration is planned for launch via rideshare on a SpaceX Falcon Heavy (STP-2), and is funded in a partnership with SCaN.

TECHNOLOGY DEMONSTRATION

FLIGHT OPPORTUNITIES

Flight Opportunities strives to mature innovative technologies of interest to NASA while simultaneously supporting the development and use of commercial services and capabilities in the U.S. aerospace industry. Flight Opportunities matures promising technologies by competitively selecting payloads through NASA Research Announcements from the broader U.S. space technology community—composed of researchers from academia, institutes, and private industry—as well as from within NASA and across other government agencies. Once technology payloads are selected, Flight Opportunities enables flight testing in relevant environments on commercial suborbital vehicles. This approach takes technologies from a laboratory environment and advances their maturity through flight demonstrations, while also supporting the small launch industry, suborbital flights and flight providers, and public-private partnerships. Currently flying for the program are UP Aerospace, Near Space Corporation, World View, Zero Gravity Corporation, and Masten Space Systems. Blue Origin and Virgin Galactic are anticipated to perform their first flight tests for the program in FY 2018.

Flight Opportunities supports technology development of interest to both NASA and the commercial space industry, and by enabling demonstration and test of new technologies using commercial flight opportunities, the program helps fulfill the goal of advancing space technology to meet future NASA exploration mission needs while simultaneously fostering the growth of the commercial spaceflight market. UP Aerospace will test both the Adaptable Deployable Entry and Placement Technology (ADEPT) and Affordable Vehicle Avionics (AVA) technologies, both under development at the Ames Research Center.

For solicitations announced in FY 2019, NASA will prioritize Flight Opportunities to align with NASA's Exploration Campaign objectives.

SMALL SPACECRAFT TECHNOLOGY

To rapidly expand the U.S. capability to execute missions, NASA uses small spacecraft technology to develop and demonstrate capabilities needed to achieve exploration missions in unique and more affordable ways. NASA invests to enable new mission architectures through the use of small spacecraft, expand the reach of small spacecraft to new destinations and challenging new environments, and to enable the augmentation of existing assets and future missions with supporting small spacecraft. Technologies demonstrated include thrusters, communications, proximity operations, and radiation sensors. NASA supports and harnesses the rapid pace of innovation in the small spacecraft community through public-private partnerships, leveraging of advances in industry and universities, and technology transfer that supports new companies and creates new lines of business. CubeSats provide a very low-cost platform to address Exploration strategic knowledge gaps.

NASA has established the Small Spacecraft Systems Virtual Institute (S3VI), hosted at NASA’s Ames Research Center in Moffett Field, California, to leverage the growing small spacecraft community, promote innovation, identify emerging technology opportunities, and provide an efficient channel for communication about small spacecraft systems with industry, academia, and other government agencies.

TECHNOLOGY DEMONSTRATION

In FY 2019, NASA will complete and deliver two CubeSats selected via the NextSTEP Phase 1: Lockheed Martin, LunIR will test an infrared sensor through a Moon flyby, and Morehead State University's Lunar IceCube will make infrared measurements of lunar volatiles. In addition to three Centennial Challenges CubeQuest Challenge awardees, NASA will deliver three additional secondary CubeSat payloads which will also fly on SLS in 2019: Lunar Flashlight CubeSat will look for lunar volatiles in shadowed craters, the BioSentinel CubeSat will study the effects of the deep space radiation environment on yeast DNA, and the Near Earth Asteroid Scout CubeSat will visit a candidate asteroid for future human exploration using a solar sail. Through industry partnership, NASA will deliver two Pathfinder Technology Demonstrator missions to expand small spacecraft capabilities for the Agency through in-space testing of new propulsion, communications, and control technologies.

NASA's CubeSat Launch Initiative provides opportunities for small satellite payloads built by universities, high schools and non-profit organizations to fly on upcoming launches. Through innovative technology partnerships NASA provides these CubeSat developers a low-cost pathway to conduct scientific investigations and technology demonstrations in space, thus enabling students, teachers and faculty to obtain hands-on flight hardware development experience.

TDM LASER COMM RELAY DEMO (LCRD)

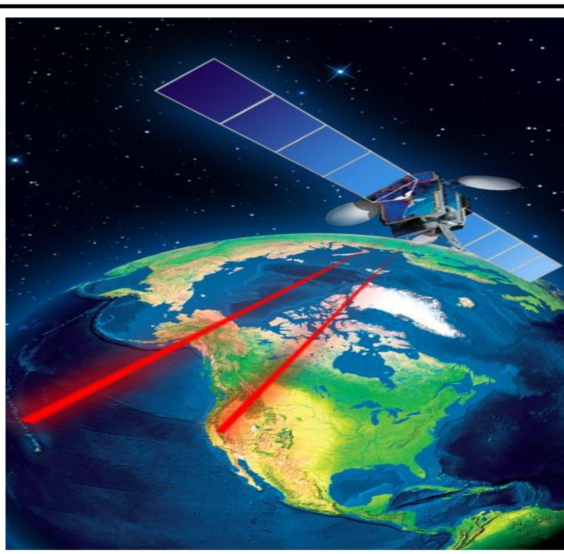
Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023	BTC	Total
Formulation	165.5	3.9	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	169.5
Development/Implementation	5.1	34.8	31.8	**20.1**	0.0	0.0	0.0	0.0	0.0	91.8
Operations/Close-out	0.0	0.0	0.0	**1.5**	0.0	0.0	0.0	0.0	0.0	1.5
2017 MPAR LCC Estimate	**170.6**	**38.7**	**31.8**	**21.6**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**262.7**
Total STMD Budget	**157.6**	**25.7**	**21.5**	**17.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**222.0**
Change from FY 2017				**0**						
Percentage change from FY 2017				**0**						
Total NASA Budget	**170.6**	**38.7**	**31.8**	**21.6**						**262.7**

FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency's current FY 2016 Operating Plan.

FY 2017 Enacted reflects the funding amounts specified in Division B of the Consolidated Appropriations Act, 2017, P.L. 115-31. Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.



The Laser Communications Relay Demonstration seeks to prove the utility of bi-directional optical communications relay services between geosynchronous orbit and Earth.

LASER COMM RELAY DEMONSTRATION

The goal of the Laser Communications Relay Demonstration project is to prove the utility of bi-directional optical communications relay services between geosynchronous orbit and Earth. The project supports the advanced communications, naviation, and avionics exploration key focus area. The outcome of this effort will prove optical communications technology in an operational setting, providing data rates up to 100-times faster than today’s radio frequency based communication systems. The demonstration will measure and characterize the system performance over a variety of conditions, develop operational procedures, assess applicability for future missions, and provide an on orbit capability for test and demonstration of standards for optical relay communications. This capability will have major implications for NASA missions, as well as crosscutting application for other agencies, and U.S. satellite manufacturers and operators given the rising

TDM LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

demand for bandwidth, consistent with the responses NASA received from the industry through a Request for Information. Set to fly as a hosted payload, this project will demonstrate an order of magnitude leap in communications capability that could be used for the architecture that succeeds today's Tracking and Data Relay Satellite satellites, and enable new capabilities and services for other government agencies and commercial space communications providers. Upon a successful flight demonstration, NASA will provide the communications industry access to the integrated system to test these new capabilities for commercial application.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

PROJECT PARAMETERS

With application to both commercial and NASA operations, LCRD will conduct a minimum two year flight demonstration to advance optical communications technology toward infusion into Near Earth operational systems, while growing the capabilities of industry sources. Objectives include:

- Demonstrating bidirectional optical communications between geosynchronous Earth orbit and Earth;
- Measuring and characterizing the system performance over a variety of conditions;
- Developing operational procedures and assessing applicability for future missions; and
- Providing an on orbit capability for test and demonstration of standards for optical relay communications.

ACHIEVEMENTS IN FY 2017

With application to both commercial and NASA operations, STMD completed Critical Design Review (CDR) and Key Decision Point C (KDP-C) for the LCRD mission.

After accomplishing environmental testing on the flight units, the project delivered one (of two) flight modems, both Optical Assemblies, Controller Electronics, and Space Switching Units to payload integration and test for integration to the flight payload on the LCRD Support Assembly, which was delivered to LCRD by Orbital ATK.

WORK IN PROGRESS IN FY 2018

The project began the physical integration of the flight payload on the LCRD Support Assembly in FY 2017 and will complete integration, perform functional and environmental testing, and deliver the flight payload to the spacecraft integrator to support a July 2018 pre-ship review.

TDM LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2019

The project will support space vehicle integration and test, including end-to-end testing with the LCRD Mission Operations Center, as well as support launch and early on-orbit checkout of the LCRD flight payload.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2019 PB Request
KDP-C	Feburary 2017	Feburary 2017
CDR	December 2016	December 2016
System Integration Review	May 2018	July 2018
KDP-D	September 2018	August 2018
KDP-E	June 2019	June 2019
Operational Readiness Review	March 2019	March 2019
Launch Readiness Review	November 2019	June 2019
Launch (or equivalent)	November 2019	June 2019

TDM LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

Development Cost and Schedule

The development cost estimate includes HEOMD/SCaN ($28.6M) funding as well as STMD ($63.1M).

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2017	63.1 (STMD)	70	2018	63.1	0	Launch	Nov 2019	June 2019	-5
2017	91.8 (NASA)	70	2018	91.8	0	Launch	Nov 2019	June 2019	-5

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	91.8	91.8	0.0
Aircraft/Spacecraft	9.9	17.3	7.4
Payloads	20.2	26.3	6.1
Systems I&T	4.1	5.7	1.6
Launch Vehicle	0.0	0.0	0.0
Ground Systems	6.3	4.7	-1.6
Science/Technology	2.6	4.1	1.5
Other Direct Project Costs	48.7	33.7	-15.0

TDM LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Program Management	Project Management, LCRD Payload, LCRD Mission Operations Center	Goddard Space Flight Center	No change
Optical Ground Station	Optical Ground Stations, RF Ground Station and STPSat-6 Mission Control Center	HEOMD/SCaN	No change
Technology Transfer	Technology Transfer for Payload	Massachusetts Institute of Technology: Lincoln Laboratory	No Change
Ground Station	Optical Ground Station 1	Jet Propulsion Lab	No Change
Spacecraft and Launch Vehicle	STPSat-6 Spacecraft and Launch Vehicle	USAF & Orbital ATK (Spacecraft vendor); ULA (Launch Vehicle)	No Change

Project Risks

Risk Statement	Mitigation
Given that the launch date slipped two months prior to the Air Force selection of a launch vehicle provider, there is risk with additional slippage beyond the 70% schedule confidence level will occur.	NASA (Project team and Space Network) is on the Senior Steering Committee for the space vehicle. This position will enable additional insight and advocacy unavailable in most hosted spacecraft arrangements. As a mission partner, NASA also has some influence on spacecraft cost increases.

Acquisition Strategy

All major acquisitions are in place.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Technology Transfer for Payload and Optical Ground Station	Massachusetts Institute of Technology: Lincoln Laboratory	Lexington, MA

TDM LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

INDEPENDENT REVIEWS

Completed Independent assessment prior to KDP-C.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Joint Confidence Level (CL)	Tecolote	Oct 2016	Determine realistic 50/70 percent CL budget and schedule IAW Agency requirements	70 percent CL used to define Program-held UFE above project for KDP-C	N/A
Standing Review Board/Independent Readiness Team	Various subject matter experts	December 8-9 (technical presentation); December 14, 2016 (Programmatic)	Provide STMD and GSFC Center Director programmatic assessment	Project has sound programmatic and technical approaches, risk plan and milestone deliverables are acceptable LCRD satisfied all review success criteria, and is ready to proceed into implementation phase	System Integration Review (SIR) that feeds into KDP-D Currently scheduled for 5/2018

HUMAN RESEARCH PROGRAM

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	140.0	--	140.0	140.0	140.0	140.0	140.0

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

NASA astronaut Peggy Whitson collects images of the back of the eye during a routine check into astronaut eyesight.

Sending astronauts into space involves a multitude of complicated systems, but perhaps the most complex is the human system – human health, human factor and the crew interaction with their environment. While NASA has more than 50 years of crew experience in low Earth orbit, researchers are continuing to unravel the mysteries of how the human body responds to the harsh environment of space. The Human Research Program (HRP) is responsible for understanding and mitigating the highest risks to astronaut health and performance to ensure crews remain healthy and productive during long-duration missions beyond low Earth orbit.

As NASA prepares to conduct crewed missions in cis-lunar space using Space Launch System (SLS) and Orion, and eventually at other locations, HRP is developing the scientific and technological expertise to send humans into deep space for longer durations. Coordinating with the National Academies, National Council on Radiation Protection and Measurements, and other domestic and international partners, HRP continues to deliver products and strategies to protect crew health and performance during and after exploration spaceflight missions. Current experiments on the International Space Station (ISS), as well as in ground-based analog environments and laboratories, are expanding our capabilities to enhance crew performance and protect the health and safety of astronauts. Investigations regarding space radiation protection, deep space habitat systems, behavioral health, innovative medical technologies, advanced food and pharmaceutical systems, space suit requirements, and validated countermeasures are evolving to ensure crew health

Space radiation poses significant health risks for crewmembers, including the possibility of developing cancer later in life, radiation sickness and cataracts during the mission, and post-mission effects on the nervous and cardiovascular systems. HRP is working with Advanced Exploration Systems (AES), Crew Health and Safety and Orion teams on both in-mission and post-mission radiation countermeasures to minimize exposures and provide radiation protection. The collaborative effort involves developing advanced radiation shielding technologies, defining permissible exposure limits, defining requirements for real-time radiation alert systems, optimizing mission architectures, radiation exposure biomedical monitoring, potential drug or nutritional countermeasures as well as incorporating post-mission health surveillance to ensure that crewmembers can safely live and work in space without exceeding acceptable radiation health risks.

In collaboration with other federal agencies, such as the Department of Defense (DoD), the Department of Energy (DOE), the National Science Foundation (NSF), the Department of Health and Human Services (HHS) and the National Institutes of Health (NIH), HRP supports human research to increase understanding of the effects of spaceflight on human physiological systems, behavioral responses to isolation and confinement, and space radiation health effects. This knowledge is critical to NASA's plans for long-duration human space missions beyond low Earth orbit. In addition, as is the case with many space-based medical investigations, this research may also lead to significant advancements in treating patients on Earth.

EXPLANATION OF MAJOR CHANGES IN FY 2019

HRP has updated its Path to Risk Reduction (PRR) to reflect more recent Human and Medical Technical Authority/Human System Risk Board assessments. HRP has finalized a new approach to support the future deep space exploration by accelerating research on risks with unknown/immature solutions, delaying research on risks associated with Mars surface operations or long-term health, and phased out research on risks that have mature mitigation solutions.

ACHIEVEMENTS IN FY 2017

Initial findings from both ISS One-Year Mission and Twins Study were presented at the annual HRP Investigator's Workshop in January. This was the first comprehensive human genomics study associated with astronauts. Whole genome sequencing showed each twin has hundreds of unique mutations in their genome, which are normal variants. Transcriptome, or ribonucleic acid (RNA) sequencing, showed more than 200,000 RNA molecules were expressed differently between the twins. Since RNA is one of four major macromolecules essential for all known forms of life, this research shows how sensitive genes are to the changing environments, in space or on Earth. Additionally, shifts in microbial species in space included a change in ratio of two dominant bacterial groups (i.e., Firmicutes and Bacteroidetes) present in the gastrointestinal tract. The ratio of one group to the other increased during flight and returned to pre-flight levels upon return to Earth. Differences in the viral, bacterial, and fungal microbiome between the twins were pronounced at all test time points due to their differing diet and environment. Both of these observations indicate a systematic adjustment of the astronaut's genetic and microbiome during spaceflight missions.

Scott Kelly and his one-year mission Russian cosmonaut counterpart, Mikhail Kornienko, both experienced a decrease in fine motor skills over time which could have operational implications on a mission to Mars. Additionally, sensorimotor dysfunction tests found vastly different performance and recovery, despite spending equal time in space. Differences suggest that a focus on preflight training and experience is beneficial. These initial observations may provide understanding of novel pathways to protect the health and performance of crews during Mars missions and other exploration missions beyond low Earth orbit.

HRP researchers conducted approximately 18 ISS biomedical research investigations during each ISS mission increment, completed seven flight investigations, and initiated three new research investigations.

HUMAN RESEARCH PROGRAM

Studies to mitigate the risk of long-duration spaceflight included a light countermeasure to help ISS and future exploration crewmembers improve sleep and enhance performance; functional immune alterations; and a study to compare the absorption, metabolism and effects of certain medication use on the ground and in the space environment.

The new Translational Research Institute for Space Health (TRI for Space Health) is operating and soliciting research as well as educating the next generation of space life scientists. TRI for Space Health awarded grants for 10 trailblazing research projects in the areas of omics, lymphatic flow, radiation damage resistance, minimally invasive surgical capabilities, and the effects of the microbiome on health during long-duration spaceflight. In addition, TRI for Space Health awarded post-doctoral fellowships to four outstanding early career scientists.

HRP started joint NASA/NSF Antarctic analog studies to support behavioral health and performance research. Working with the NSF Polar Program, HRP is integrating behavioral health and performance research studies into the Antarctic winter-over campaign sites that serve as operational research analogs by providing long duration, isolation, confinement, and extreme conditions to stress the research participants. The first study occurred during the 2017 winter-over and included approximately 110 U.S. Antarctic program volunteers located at the McMurdo and South Pole stations. Volunteers completed periodic computer-based questionnaires, provided saliva samples, and wore a monitor that recorded sleep and wake cycles. Researchers used these collective tools to look for signs of stress and changes in psychological health of the volunteers during their time in Antarctica. Research in these areas has obvious benefits for living in space but could also prove beneficial to people living and working under similar conditions on Earth.

HRP began joint NASA/German Aerospace Center (DLR) analog studies to support human health countermeasures, exploration medical and behavioral health and performance research. Working with the DLR Space Agency and the DLR Institute for Aerospace Medicine, NASA will integrate these studies into future Human Exploration Research Analog (HERA) missions at Johnson Space Center, and DLR is integrating NASA studies into their bed rest campaigns being conducted in their state of the art envihab medical research facility located in Cologne, Germany. HRP is studying bed rest as an experimental analog for space flight because extended exposure to a head-down tilt position can duplicate many of the effects of a low-gravity environment.

HRP delivered a real-time crew performance assessment tool, which should prove very useful in gathering near real-time human factors and habitability data during spaceflight missions that can be applied to the designs of next generation spacecraft and habitats. Prior to this, there had been no established methods in existence to collect real-time human factors and habitability data. Instead, these memory-contingent data were acquired at the end of missions during post-flight crew debriefs, which typically occur weeks after the events have occurred. Observations during the ISS One-year mission, as well as six-month missions, can help spacecraft designers understand how much habitable volume is required, and whether a mission’s duration impacts how much space crew members need.

WORK IN PROGRESS IN FY 2018

HRP will continue to work on the highest human health and performance risk areas associated with human space exploration missions. To support this work, HRP will release NASA research solicitations to the national biomedical research community to better address the exploration spaceflight health, performance, and space radiation risks; implement a research plan that fully utilizes the ISS biomedical research capabilities to test mitigation approaches and validate countermeasures; and leverage resources and expertise through collaborative research with other NASA programs, international partners and other U.S. agencies such as DoD, DOE, NSF, HHS and the NIH.

HRP will undertake risk mitigation activities associated with long-duration human spaceflight that address medical consumables tracking technology to better understand pharmaceutical countermeasure effectiveness; develop improved injury assessment models to better protect crew during dynamic phases of flight; protect team function and performance during the isolation and confinement of long-duration missions; improve the physiological medical standards to better protect muscle and aerobic capacity; and deliver an improved cancer risk projection model for operational use to protect crew from space radiation risks. Finally, HRP is helping improve the health of our nation's children by continuing the annual Train Like an Astronaut Fitness Challenge which will be in its eighth year and was developed in cooperation with NASA scientists and fitness professionals working directly with astronauts.

HRP will begin the Spaceflight Standard Measures project that will collect a set of core measurements, representative of many of the human spaceflight risks from astronauts before, during and after long-duration ISS missions. The project is designed to acquire a consistent set of validated measured parameters that document the spaceflight normal response as well as variation in the astronaut population in response to diverse duration exposures to spaceflight. The main aim is to ensure that an optimized minimal set of measures is consistently captured from all ISS crewmembers in order to characterize the health of a human in space. The results will function as a data repository and be available to investigators to develop hypotheses, provide supporting experimental data, or be used in astronaut and Earth-based epidemiology population.

HRP will continue to support research at the NASA Space Radiation Laboratory (NSRL). Early 2017 was the first time NASA used the NSRL galactic cosmic ray (GCR) simulator along with proton and heavy ion beams. In the past, accelerator-based space radiation experiments were performed with single ion beams at fixed energies. With the GCR, HRP is able to utilize beam switching technology which means it is now possible to rapidly switch ion species and energies, allowing for a more realistic possibility to simulate the actual radiation environment found in space.

HRP participated in a research study at the DLR Institute of Aerospace Medicine's :envihab facility, which will provide support to the HRP-funded investigators whose studies were also implemented in the facility. The objective of the study is to determine whether 30 days of bed rest at a six-degree head-down tilt under elevated carbon dioxide exposure, similar to what is experienced on the ISS and could occur on future exploration missions, affects physiological and psychological functions.

HRP will collaborate with Crew Health and Safety on ISS studies related to visual impairment, carbon dioxide analysis, exercise systems and cognitive functions measures.

HRP will continue to assess deep space habitat concepts under the Next Space Technologies for Exploration Partnerships (NextSTEP) Phase 2 Broad Agency Announcement. The overall purpose is to develop and evaluate a government habitat reference architecture in order to prepare to assess industry-provided habitat mockups. HRP will contribute an integrated demonstration of crew exercise to evaluate habitat architecture accommodations to support crew exercise. HRP will do this through the medical data architecture (MDA) which is a prototype system to comprehensively manage and process medically-relevant information to support exploration medical operations, and with a novel "Astroskin" biosensor provided by the Canadian Space Agency that is a wearable vest that collects biometric information such as heart and breathing rates.

HRP will deliver recommended updates to physiological medical standards to better protect muscle and aerobic capacity. HRP will also deliver recommendations on methods to maintain team function and performance during isolation and confinement of long-duration missions.

Since access to ISS crews is limited by the number of astronauts who fly and time requirements for operations, HRP relies on ground analogs to mitigate some risks. HRP will conduct four 45-day isolation study campaigns using the Human Exploration Research Analog (HERA) facility. HERA is a unique three-story habitat designed to serve as an analog for isolation, confinement, and remote conditions in exploration scenarios. Each HERA campaign uses crews of four and is supported by a mission control team. A variety of experiments are supported during each 45-day simulated mission.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

HRP intends to fully utilize ISS by implementing an ISS flight research plan critical to mitigating crew health and performance risks for exploration missions. HRP will continue planning with the ISS program for additional one-year missions to validate exploration countermeasures. HRP will also develop and complete ground testing of an advanced exploration exercise system in preparation for ISS deployment as part of exploration system maturation plans.

HRP will continue work with NASA's Deep Space Exploration Habitation development to define and evaluate exploration habitats. HRP will evaluate habitats for accommodation of exercise device and prototype autonomous medical systems. HRP has identified several opportunities for testing and system integration and will continue working with the NASA team on test planning, execution, and evaluation.

HRP will continue leveraging resources through multiple partnerships including international partnering on isolation, confinement and physiology studies with Russia, DLR and European Space Agency. HRP plans to continue discussions will DLR on future bed rest studies to be held in FY 2018 at the :envihab facility in Cologne, Germany and discussing potential opportunities for collaboration and data sharing with European investigators.

HUMAN RESEARCH PROGRAM

Program Elements

EXPLORATION MEDICAL CAPABILITY

As NASA makes plans to extend human exploration beyond low Earth orbit, identifying and testing next-generation medical care and crew health maintenance technologies is vital. Health care options evolve based on experience, anticipated needs, and input from flight surgeons and crew offices. Crews will not be able to rely on real-time conversations with Earth-based medical experts in the future due to communication lag-time associated with the distance between Earth and deep space. Therefore, crew and relevant systems must be able to facilitate autonomous medical care operations. Teams in this area draft requirements for medical equipment and clinical care, develop remote medical technologies and assess medical requirements unique to long-duration space missions.

HUMAN HEALTH COUNTERMEASURES

Countermeasures are the procedures, medications, devices and other strategies that offset the impacts of spaceflight stressors (e.g., low gravity, high radiation, etc.) and help keep astronauts healthy and productive during space travel and after their return to Earth. Researchers provide biomedical expertise; they are responsible for understanding the normal physiologic effects of spaceflight, and then developing countermeasures to those with harmful effects on human health and performance. These experts define health and medical standards, validate human health prescriptions and exercise system requirements, develop injury and sickness prevention standards, integrate and validate physiological countermeasures, and establish criteria for NASA fitness for duty, as well as crew selection and performance standards.

HUMAN FACTORS AND BEHAVIORAL PERFORMANCE

Just as the space environment poses physical risks to crewmembers, the unique stresses and challenges of spaceflight as well as the vehicle design can affect cognitive and mental performance. Considering external factors is essential when designing a spacecraft, habitat, or spacesuit. Human factors experts develop new equipment, procedures, and technologies designed to make the space environment more livable. Behavioral health researchers assess the impact of space travel on human behavioral health, and develop interventions and countermeasures to ensure optimal health and performance. Experts in this area make extensive use of analogs, which are experimental environments created to simulate certain aspects of space travel. By duplicating space conditions, such as altered day and night cycles, heavy workloads, social isolation, and close living quarters, scientists gain insight into the impact of these circumstances on human behavior and performance. They then work to develop countermeasures, equipment, and other interventions to minimize these risks.

SPACE RADIATION

As NASA expands human presence through the solar system, it is critical that crews are able to safely live and work in a space radiation environment without exceeding exposure limits. Space radiation researchers develop the knowledge base necessary to determine the biological effects of space radiation. This information can then be used for standards for health and habitability, and the requirements for radiation protection. They also develop tools to assess and predict risks due to space radiation exposure, and strategies to mitigate exposure effects. The deep space radiation environment is far different from that on

Earth or in low Earth orbit. Thus, NASA and the DOE have partnered on a facility at Brookhaven National Laboratory in New York to simulate the deep space radiation environment which researchers use to help understand its biological effects.

ISS MEDICAL PROJECTS

The ISS provides a unique testbed for HRP activities. The medical projects team plans, integrates, and implements approved biomedical flight experiments on the ISS, as well as research studies that use ground-based spaceflight analog facilities to accomplish program objectives. This includes pre and post-flight activities, coordinating flight or ground resources with our international partners, maintaining ISS biomedical research racks and flight hardware, and developing crew training for both flight and ground investigations. Teams also operate a telescience support center, which provides real-time support and data services to all HRP flight experiments. Strong interfaces with external implementing organizations, such as the ISS payloads office, analog coordination offices, and international partners, are critical to maintaining a robust research program. This group is also responsible for operating the HERA analog facility at NASA-Johnson Space Center (JSC) and arranging access to other analog facilities required by HRP researchers, including NSF Antarctic facilities, other national isolation analogs, and international partner facilities in Germany and Russia.

Program Schedule

Date	Significant Event
Oct 2017	Release NASA Cancer Risk Model Source Code 2017 to Operations via access to software repository including documentation and use cases for validation
Dec 2017	Complete recommendations to Health Maintenance System (HMS) based on Medical Consumables Tracking (MCT) flight demonstration
Jan 2018	Complete Team Function and Performance Protocol Recommendations to the Flight Activities Control Board (FACB) for Long Duration Spaceflight
Jan 2018	Conduct 2018 HRP Investigators' Workshop
Mar 2018	Complete updates to Aerobic and Muscle Standard recommendations for Health and Medical Technical Authority (HMTA) based on the fitness for Mission Task studies
Mar 2018	Anthropomorphic Test Device injury assessment reference values to mitigate crew injury during dynamic phase of flight
April 2018	Complete First Campaign of 4-45 day HERA Missions
May 2018	Develop Computational Model for Spacecraft/Habitat Volume (Thaxton/NRA)
May 2018	Release Human Exploration Research Opportunity 2017 (HERO) NASA Research Announcement Selection
Aug 2018	Release 2018 HERO 2018 NASA Research Announcement

HUMAN RESEARCH PROGRAM

Program Management & Commitments

The program office is located at JSC with support from Ames Research Center (ARC), Glenn Research Center (GRC), Langley Research Center (LaRC), and Kennedy Space Center (KSC).

The Human Exploration and Operations Associate Administrator delegated the authority, responsibility, and accountability of HRP management to the Space Life and Physical Sciences Research and Applications (SLPSRA) Division at NASA Headquarters. Working closely with the Office of the Chief Scientist, and the Office of the Chief Health and Medical Officer, the SLPSRA Division establishes the overall direction, scope, budget, and resource allocation for the program which the NASA centers then implement.

Program Element	Provider
Exploration Medical Capability	Provider: JSC Lead Center: JSC Performing Center(s): GRC, ARC, and LaRC Cost Share Partner(s): N/A
Human Health Countermeasures	Provider: JSC Lead Center: JSC Performing Center(s): ARC and GRC Cost Share Partner(s): N/A
Human Factors and Behavioral Performance	Provider: JSC Lead Center: JSC Performing Center(s): ARC, GRC, and KSC Cost Share Partner(s): N/A
Space Radiation	Provider: JSC Lead Center: JSC Performing Center(s): LaRC Cost Share Partner(s): N/A
ISS Medical Project	Provider: JSC Lead Center: JSC Performing Center(s): ARC and KSC Cost Share Partner(s): N/A

Acquisition Strategy

Based upon National Academies' recommendations, external peer reviews, and Agency human exploration plans, NASA HRP awards contracts and grants to further efforts in mitigating risks to crew health and performance by providing essential biomedical research and technologies for human space

HUMAN RESEARCH PROGRAM

exploration. HRP uses a peer review process that engages leading members of the research community to competitively assess the merits of submitted proposals to assure a high-quality research program.

HRP plans to release the Human Exploration Research Opportunities umbrella NRA that will request research proposals across all of its research elements throughout the year, including Space Radiation and Crew Health and Performance. This NRA provides opportunities for universities, other government agencies and industry researchers from across the nation to develop high NASA priority ground and spaceflight experiments which directly contribute to NASA's exploration mission.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Program Management	Translational Research Institute	Baylor College of Medicine

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	National Academies	Jun 2016	Review of NASA research on human health risks	Informed program research prioritization	Jun 2018
Quality	National Council on Radiation Protection (NCRP)	Jul 2016	Review of space radiation health risks	Established research priorities for space radiation research	Jul 2018
Quality	Peer Review Panel	Jul 2017	Peer review of NRA	Selected grantees	Jul 2018
Quality	Independent Program Assessment	Sep 2015	Review of program management policies and practices	Verified adherence to NASA program management policies	Sep 2018

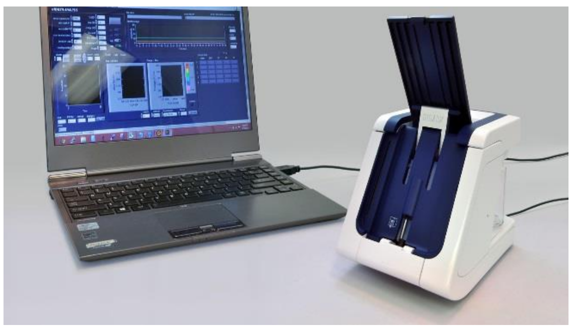
SBIR AND STTR

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**199.0**	**--**	**205.0**	**198.0**	**198.0**	**198.0**	**198.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



NASA had been searching for ways to monitor the health of astronauts during long missions using tests that would be easy to administer, would not be intrusive nor require guidance from Mission Control. DNA Medicine Institute, a med-tech incubator, laboratory, and biomedical technology service provider based in Cambridge, MA, developed a comprehensive nanoscale diagnostic platform help make self-diagnosis in outer space a reality and revolutionizing the overall approach to medical testing.

NASA’s Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs leverage the Nation’s innovative small business community to support research and development in support of NASA's mission in human exploration, science and aeronautics. These programs provides the small business sector with an opportunity to develop technology for NASA, and to commercialize that technology to spur economic growth.

The Agency actively works to facilitate the infusion of NASA-funded SBIR and STTR technologies into its missions and projects. Research and technologies funded by SBIR and STTR contracts have made important contributions to the Agency’s mission. Examples include in-space propulsion systems to reduce travel time and cost; research to revolutionize space travel with new technologies to generate electrical power and store energy; technologies to enable a growing number of potential applications for small spacecraft; and advances in instruments that can be used as inspection tools for locating and diagnosing material defects like a micro meteoroid impact.

Small Businesses are contributing to NASA's mission through advancements in robotic mobility, manipulation, and sampling, as well as technologies for breaking through barriers to enable greater use of Unmanned Aircraft Systems in NASA research and in civil aviation. These investments seek to achieve the program’s vision of empowering small businesses to deliver technological innovation that contributes to NASA’s interests, provides societal benefit, and grows the U.S. economy.

SBIR AND STTR

EXPLANATION OF MAJOR CHANGES IN FY 2019

Beginning FY 2019, SBIR and STTR annual solicitations will emphasize Exploration Campaign technology focus areas while continuing to support subtopics developed by the Science and Aeronautics Mission Directorates.

ACHIEVEMENTS IN FY 2017

- NASA conducted its first Request for Information (RFI) to seek feedback from firms about the 2017 subtopics, ideas for new subtopics and programmatic feedback. The RFI resulted in over 270 ideas for new subtopics, over 100 pieces of feedback on subtopics from the FY 2017 solicitation, with over 150 small businesses responding to questions about programmatic improvements. 89 percent of respondents said they would participate annually in an RFI, demonstrating the desire for engagement by small businesses. Numerous ideas submitted through the RFI were incorporated into the 2018 solicitation, including improvements to the budget form and providing a one-stop-shop for submitting New Technology Reports.
- NASA conducted its second Industry Day, held both at the Ames Research Center and virtually, to increase engagement with current and potential participants in the program. Over 450 innovators from across the country participated. The workshop was held for informational purposes and was an opportunity for the small business community to explore and share ideas related to the general technical topic areas. It also provided a forum for feedback that resulted in a more integrated, streamlined 2018 SBIR solicitation.
- NASA received 1,621 proposals in response to the 2017 SBIR and STTR solicitation and selected 399 Phase I awards valued at $49.9 million. Women-Owned Small Businesses represented 9.1 percent of the awards and Small, Disadvantaged Businesses received 8.5 percent of the awards, and approximately 75 percent of awards went to companies with fewer than 50 employees. The 2017 solicitation contained small satellite and small launch vehicle technologies as a new topic to address the needs of the academic and commercial small satellite communities with a goal of five percent of SBIR/STTR program funding. 23 Phase I awards (5.7% of all Phase I awards) were made for the small satellite and small launch vehicle topics.
- 133 SBIR Phase II proposals were selected for contract negotiation valued at nearly $100 million. Over six percent of those awards were to Women-Owned Small Businesses and over 10 percent were to Small, Disadvantaged Businesses. Awards from these solicitations include: technologies to create the advanced structures needed for future deep space missions and next-generation aeronautics capabilities; and significantly reducing the size and weight of object-detection sensors, with applications ranging from autonomous aircraft to space missions, and technologies to allow constellations of individual satellites to fly in precise formation and perform coordinated science, enabling new capabilities such as autonomous rendezvous and docking, and precision formation flying both for human and robotic exploration missions.
- Phase II STTR program selected 19 proposals for contract negotiation valued at nearly $14.3 million. Over five percent of those awards were to Women-Owned Small Businesses and over five percent were to Small, Disadvantaged Businesses.
- 30 SBIR Phase II E/X were transitioned to commercialization through awards valued at over $7.9 million, along with eight STTR Phase II E/X awards valued at over $2.1 million. In addition, the program initiated a new Civilian Commercialization Readiness Pilot Program (CCRPP) to further advance innovative technology with high potential for commercial impact. In FY 2017 NASA selected 16 CCRPP awards valued at over $9.5 million which brought more than $9.5 million in

matching funding. Finally, over $10 million was infused into SBIR and STTR companies through utilization of their NASA awarded technologies with 47 Phase III awards.

- To enable small businesses to commercialize their innovations, NASA established an interagency agreement with the National Science Foundation to provide training grants for participation in the I-Corps program to six SBIR and five STTR Phase I awardees from the 2017 solicitation.

WORK IN PROGRESS IN FY 2018

- The FY 2018 annual solicitation was released in January. NASA plans to award new Phase I and Phase II SBIR and STTR selections in May 2018.
- NASA will continue to seek small business feedback to increase collaboration with small businesses through an annual industry day and Request for Information.
- NASA will continue to offer Post-Phase II award opportunities through vehicles like the Phase II E/X and CCRPP programs to increase technology transitions and commercialization. In addition, NASA will continue to make I-Corps training grants awards for Phase I awardees to encourage commercialization of technology funded through awards.
- The program will roll out an operational and technical modernization effort that is driven by the SBIR and STTR users and leverages today's technology. NASA conducted more than 100 input sessions throughout FY 2017 and 2018 to inform this modernization effort including: interviews, design sessions, and suggestions from Industry Day and on our website. The program also received about 400 submissions to our RFI.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

- Starting with the FY 2019 solicitations, the new Exploration Research and Technology organization will emphasize topics on long-term human exploration and space utilization consistent with the Exploration Campaign. The SBIR and STTR Programs will continue to work with the other NASA mission directorates, centers and industry to identify subtopics. NASA plans to release the annual SBIR and STTR solicitations in January 2019, and award new Phase I and Phase II selections the following summer.
- NASA will continue to offer Post-Phase II award opportunities to increase technology transitions and commercialization; and modernize its business capabilities to reduce barriers to entry for firms, to increase the quality of proposals and to improve the value proposition for firms.
- NASA will pilot opportunities to accelerate the program's ability to advance NASA interests in deep space exploration and those of the commercial aerospace sector.

Program Elements

SBIR

The SBIR program was established by statute in 1982 and was reauthorized in 2016 to increase research and development opportunities for small businesses. The program stimulates U.S. technological innovation, employs small businesses to meet federal research and development needs, increases the ability for small businesses to commercialize innovations they derive from federal research and

SBIR AND STTR

development, and encourages and facilitates participation by socially disadvantaged businesses. In FY 2018, the SBIR program is supported at a level of at least 3.2 percent of NASA's extramural research and development budget. In FY 2019, the maximum value for an SBIR Phase I contract will be $125,000 for a period of performance of six months. For Phase II, the maximum total value of an SBIR award will be $750,000 over a 24-month period of performance. NASA also supports Phase II Enhancement (II-E/X) contract options with incentives for cost sharing to extend the research and development efforts of the current Phase II contract. NASA also supports Civilian Commercial Readiness Pilot Program (CCRPP) contracts with incentives for cost sharing to extend the research and development efforts of the previous Phase II contract with strong customer pull for technology maturation. NASA also supports I-Corps training grants for Phase I awardees to enable small businesses to commercialize their innovations through an interagency agreement with the National Science Foundation.

STTR

The STTR program was established by statute in 1992 and was reauthorized in 2016 to award contracts to small businesses for cooperative research and development with a non-profit research institution, such as a university. NASA's STTR program facilitates transfer of technology developed by a research institution through the entrepreneurship of a small business, resulting in technology to meet NASA's core competency needs in support of its mission programs. Modeled after the SBIR program, STTR is funded based on 0.45 percent of the NASA extramural research and development budget. In FY 2019, the maximum value for an STTR Phase I contract is $125,000 for a period of performance of thirteen months. For Phase II, the maximum total value of an STTR award is $750,000 over a 24-month period of performance. Phase II-E/X contract options, CCRPP, and I-Corps are also available to STTR participants.

SBIR AND STTR

Program Schedule

SBIR and STTR solicitation and award schedule is below.

Date	Significant Event
January 2018	2018 SBIR and STTR Phase I Solicitation Opens
March 2018	2018 SBIR and STTR Phase 1 Solicitation Closes
May 2018	2018 SBIR and STTR Phase 1 Awards
March 2018	SBIR Phase II Awards Selected (from 2017 Phase I Awards)
July 2018	STTR Phase II Awards Selected (from 2017 Phase I Awards)
August 2018	2019 Solicitation Topics Requested from Mission Directorates and Centers
January 2019	2019 SBIR and STTR Phase I Solicitation Opens
March 2019	2019 SBIR and STTR Phase 1 Solicitation Closes
May 2019	2019 SBIR and STTR Phase 1 Awards
April 2019	SBIR Phase II Awards Selected (from 2018 Phase I Awards)
October 2019	STTR Phase II Awards Selected (from 2018 Phase I Awards)
August 2019	2020 Solicitation Topics Requested from Mission Directorates and Centers

Program Management & Commitments

Program Element	Provider
SBIR and STTR	Provider: Various Small Businesses and their research partners Lead Center: NASA HQ; Level 2: Ames Research Center (ARC) Performing Center(s): All centers play a project management and implementing role. Cost Share Partner(s): SBIR Phase II-E/X matches cost share funding with SBIR and STTR up to $375,000 of non-SBIR and non-STTR investment(s) from a NASA project, NASA contractor, or third party commercial investor to extend an existing Phase II project to perform additional research. SBIR CCRPP matches cost share funding with non-SBIR and non-STTR investment(s) from a NASA project, NASA contractor, or third party commercial investor to continue a former Phase II project to perform additional research for strong customer pull for the technology maturation.

SBIR AND STTR

Acquisition Strategy

NASA issues annual SBIR and STTR program solicitations, setting forth a substantial number of topic areas open to qualified small businesses. There are three phases for SBIR and STTR funding awards. Phase I awards give small businesses the opportunity to establish the scientific, technical and commercial merit of the proposed innovation in alignment with NASA interests. The most promising Phase I projects are selected for Phase II awards through a competitive selection process, based on scientific and technical merit, expected value to NASA, and commercialization potential. Phase II awards focus on the development, demonstration, and delivery of the proposed innovation. Phase II Enhancement (II-E/X) and the Civilian Commercialization Readiness Pilot Program support advancement of innovations developed under Phase II. Phase III supports the commercialization of innovative technologies, products, and services that result from a Phase I or Phase II contract. Commercialization includes further development of technologies and getting feedback to discover infusion opportunities into NASA programs, other government agencies, or the private sector. Phase III contracts receive funding from sources other than the SBIR and STTR programs and may be awarded without further competition.

SBIR and STTR program management work collaboratively with NASA Center Chief Technologists (for STTR) and a Mission Directorate Steering Council (for SBIR) during the SBIR and STTR acquisition process. This collaboration, from topic development through proposal review and ranking, supports final selection. Mission Directorates and NASA center program personnel interact with SBIR and STTR award winners to maximize alignment and implementation of the SBIR and STTR products into NASA's future missions and systems. The Space Technology Mission Directorate (which will be part of the new ER&T) oversees the writing of SBIR and STTR topics and subtopics to address NASA's core competencies and align with the Agency's Technology Roadmaps.

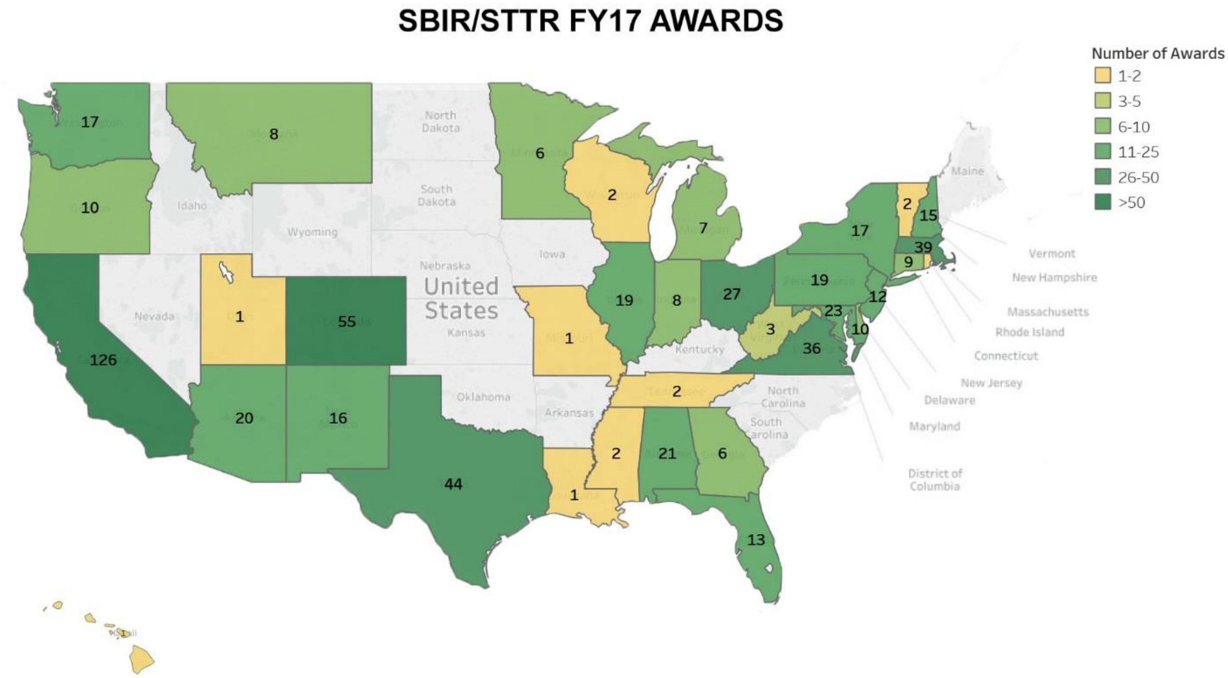
INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Government Accountability Office (GAO)	Ongoing	The GAO has been tasked to assess all SBIR and STTR programs for their performance in complying with spending requirements, and program efforts in combating Waste, Fraud, and Abuse.	GAO found no concerns to address.	Ongoing

SBIR AND STTR

Historical Performance

The map below represents the FY 2017 SBIR and STTR Phase I, Phase II, Phase II-E/X, and CCRPP that target technologies highly desired by NASA Mission Directorates, by geographic location.



LEO AND SPACEFLIGHT OPERATIONS

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
International Space Station	1450.9	--	**1462.2**	1453.2	1471.2	1466.2	1451.2
Space Transportation	2589.0	--	**2108.7**	1829.1	1858.9	1829.2	1807.3
Space and Flight Support (SFS)	902.6	--	**903.7**	841.4	888.2	934.9	954.6
Commercial LEO Development	0.0	--	**150.0**	150.0	175.0	200.0	225.0
Total Budget	**4942.5**	**4850.1**	**4624.6**	**4273.7**	**4393.3**	**4430.3**	**4438.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

LEO AND SPACEFLIGHT OPERATIONS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
International Space Station	1450.9	--	**1462.2**	1453.2	1471.2	1466.2	1451.2
Space Transportation	2589.0	--	**2108.7**	1829.1	1858.9	1829.2	1807.3
Space and Flight Support (SFS)	902.6	--	**903.7**	841.4	888.2	934.9	954.6
Commercial LEO Development	0.0	--	**150.0**	150.0	175.0	200.0	225.0
Total Budget	**4942.5**	**4850.1**	**4624.6**	**4273.7**	**4393.3**	**4430.3**	**4438.0**
Change from FY 2018			**-225.5**				
Percentage change from FY 2018			**-4.6%**				

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

NASA astronauts Kate Rubins (left) and Jeff Williams (right) prepare to grapple the SpaceX Dragon supply spacecraft from aboard the International Space Station.

The Budget proposes to centralize space access efforts in a new Low Earth Orbit (LEO) and Spaceflight Operations account, enabling NASA to better plan both government and commercial access to space, and laying the foundation to support future commercial operations in LEO. These activities support existing and future space operations, commercialization, and space and flight support capabilities for NASA and non-NASA missions.

The FY 2019 President's Budget includes a new account structure for the human space exploration and technology program to improve the alignment of funding with NASA's new strategic space exploration objectives. It renames the Space Operations, Exploration, and Space Technology accounts as LEO and Spaceflight Operations, Deep Space Exploration Systems, and Exploration Research and Technology, and realigns some program funding. As part of this realignment, NASA also plans to restructure the Human Exploration and Operations Mission Directorate and Space Technology Mission Directorate.

The new Commercial LEO Development theme and program will fund NASA's efforts to assist commercial space industry in developing a long-term, sustained commercial LEO presence. NASA’s efforts will focus on enabling, developing, and deploying commercial platforms. The Budget proposes to end direct U.S. financial support for the International Space Station (ISS) in 2025, after which NASA would rely on commercial partners for its LEO research and technology demonstration requirements. To kick off the new program's activities, NASA plans to request formal proposals from industry for future platforms and capabilities. We are expecting to see market analysis and business plans as part of these proposals.

LEO AND SPACEFLIGHT OPERATIONS

While initiating planning to transition LEO human spaceflight operations to commercial partners in 2025, NASA will continue existing operations of the ISS with expanded partnerships on the station. Over the next seven years, these partnerships – international and commercial – will help ensure continued human presence in LEO and full utilization of ISS for conducting research and technology development.

ISS serves as a platform for advanced human systems research and technology which enables safe and reliable exploration beyond LEO. As a national research laboratory, ISS leverages global collaboration and commercial partnerships to advance our Nation's and world's capabilities in space and help open the space frontier. ISS provides opportunities for U.S. companies to further enhance their experience and business base in LEO. Programs in the LEO and Spaceflight Operations portfolio support and expand commercialization as the foundation of future U.S. civilian space efforts, including promoting new opportunities for collaboration with industry on space station operations.

The Crew and Cargo Program manages transportation services provided by both international partners and domestic commercial providers. NASA continues to advance commercial spaceflight and the American jobs it creates.

Commercial Crew Program (CCP) partnerships with the private sector are working to develop and operate safe, reliable, and affordable crew transportation systems capable of carrying humans to and from space, including the ISS. Working with industry to develop and provide human transportation services to and from space will lay the foundation for more affordable and sustainable future human space transportation capabilities, bolster American leadership, reduce our current reliance on foreign providers for this service, and help stimulate the American aerospace industry.

Space and Flight Support programs continue providing mission critical space communications, launch and test services, and astronaut training to support their customer missions. The Space Communications and Navigation program provides communication with missions in LEO and ISS with the Space Network. The Near Earth Network communicates with suborbital missions and some lunar orbits, while the Deep Space Network communicates with the missions most distant from Earth. The Launch Services Program provides expertise and active launch mission management for over 40 NASA and other civil sector government missions in various stages of development. The Rocket Propulsion Test program manages a wide range of facilities capable of ground testing rocket engines and components under controlled conditions, a critical foundation for the success of NASA and commercial missions. To continue with the next step in human space exploration, NASA must prepare the human system for living and working in the hostile environment of space. The Human Space Flight Operations program provides the training and readiness to ensure crew health, safety and mission success.

For further programmatic information, go to https://www.nasa.gov/directorates/heo/index.html

INTERNATIONAL SPACE STATION PROGRAM

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
ISS Systems Operations and Maintenance	1103.5	--	**1105.5**	1105.5	1105.6	1105.6	1105.6
ISS Research	347.3	--	**356.7**	347.7	365.6	360.6	345.6
Total Budget	**1450.9**	**--**	**1462.2**	**1453.2**	**1471.2**	**1466.2**	**1451.2**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

NASA Astronaut Mark Vande Hei is pictured tethered to the outside of the U.S. Destiny laboratory module during a spacewalk on October 10, 2017.

The International Space Station (ISS) is the largest and most complex habitable space-based research facility ever constructed by humanity. This highly complex facility provides a unique platform, enabling distinct research opportunities. The ISS's crew members orbit the Earth about every 90 minutes and have continuously occupied the facility since 2000. The U.S. segment is the portion of ISS operated by the U.S. and its Canadian, European, and Japanese partners. Russia exclusively operates the Russian segment.

The ISS spans the area of a U.S. football field (with end zones) and weighs over 860,000 pounds. Its solar arrays, which help power the vehicle, are longer than a Boeing 777's wingspan at 240 feet. The ISS has eight docking ports for visiting vehicles delivering crew and cargo. Orbiting Earth 16 times per day at a speed of 17,500 miles per hour, the ISS maintains an altitude that ranges from 230 to 286 miles. The complex has more livable room than a conventional five-bedroom house, with two bathrooms, a fitness center, a 360-degree bay window, and state of the art scientific research facilities. In addition to external test beds, the U.S. operating segment of the ISS houses three major science laboratories (U.S. Destiny, European Columbus, and Japanese Kibo).

NASA will continue its existing operations and further expand partnerships on the ISS. Direct federal support for ISS under the current NASA directed model will end in 2025, though industry could potentially continue to operate certain elements or capabilities where NASA is one of many customers. NASA will expand international and commercial partnerships over the next seven years in order to ensure continued human presence in low Earth orbit (LEO) and to expand demand for the commercial market in LEO. More information on NASA's budgetary and programmatic support for commercial options to fulfill research, science and technology requirements beyond ISS such as commercial orbital platform(s) can be found in the LEO Commercial Development section. The four major focus areas of activity for the ISS program include helping to return benefits to

INTERNATIONAL SPACE STATION PROGRAM

humanity on Earth through space-based research and technology development, serving as a key stepping stone on the pathway to deep space exploration, enabling the development and advancement of a commercial marketplace in low Earth orbit, and maintaining U.S. global leadership of space exploration. Through its international and domestic partnerships, the program continues to build relationships to further expand expertise in a myriad of scientific fields to benefit humanity.

The ISS will facilitate moving human space exploration from an Earth-reliant to an Earth-independent capability, a shift necessary for true deep space exploration. The ISS is currently the only microgravity platform that can enable the long-term testing of new life support and crew health systems, advanced habitation modules, and other technologies needed to decrease reliance on Earth. Over the next several years, the program will continue to focus on capabilities needed to maintain a healthy and productive crew in deep space. Manifested or planned experiments and demonstrations include tests of improved long-duration life support for deep space missions beyond LEO, advanced fire safety equipment, on-board environmental monitors, techniques to improve logistics efficiency, in-space additive manufacturing, advanced exercise and medical equipment, radiation monitoring and shielding, human-robotic operations, and autonomous crew operations. The facility enables scientists to identify and quantify risks to human health and performance, and to develop and test preventative techniques and technologies to protect astronauts during extended time in space. The ISS platform also provides a rich environment for endless research possibilities in the areas of fundamental biological and physical sciences.

The ISS program aims to provide direct research benefits to the public through its operations, research, and technology development activities. As a National Laboratory, the U.S. segment of the ISS enables partners in government, academia, and industry to utilize its unique environment and advanced facilities to perform investigations. The ISS National Laboratory program is managed by the Center for the Advancement of Science in Space (CASIS). The focus of CASIS is to increase utilization of the ISS U.S. segment by providing access to academia, the commercial sector, and other Government agencies through partnerships, cost-sharing agreements, and other arrangements for research, technology development, low Earth orbit commercialization, and education. Observing from and experimenting aboard, the ISS provides the opportunity to learn about Earth, life, and the solar system from a very different perspective. NASA and its partners also use this unique reference point to advance science, technology, engineering, and mathematics efforts to inspire youth to pursue those fields. The results of the research completed on the ISS can be applied to many areas of science, improving life on this planet, and furthering the experience and increased understanding necessary to journey to other worlds. Innovative ISS research is of incredible value to the U.S. and its citizens, making the ISS a worthwhile investment for the country.

For additional information on the ISS program, go to https://www.nasa.gov/mission_pages/station/main/index.html.

For specific information on the many experiments conducted on ISS, go to https://www.nasa.gov/mission_pages/station/research/experiments_category.html.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	FY 2020	Notional FY 2021	FY 2022	FY 2023
Total Budget	**1103.5**	**--**	**1105.5**	**1105.5**	**1105.6**	**1105.6**	**1105.6**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

NASA astronaut Shane Kimbrough is seen inside the Quest airlock on January 13, 2017, during his pre-breathe session prior to a spacewalk. Astronauts breathe 100% oxygen prior to a spacewalk to help purge excess nitrogen from their blood stream and avoid decompression sickness.

The International Space Station (ISS) is a complex research facility and human outpost in low Earth orbit developed in a collaborative, multinational effort led by the U.S. with partners in Canada, Europe, Japan, and Russia. The facility's primary goals are to advance exploration of the solar system, enable unique scientific research, and promote commerce in space with industry partners as new commercialization concepts are explored. The Operations and Maintenance (O&M) project supports vehicle operations in the harsh conditions of space with constant, around-the clock-support. The ISS systems operate in extreme temperatures, pressures, and energies that challenge engineering techniques with minimal margin for error. The risks associated with operating the ISS are critical and must be effectively managed to protect against catastrophic consequences to mission success and human life.

Safely operating the ISS in the severe conditions of space and ensuring the crew always have a sufficient supply of food, water, oxygen, and repair parts, demands precise planning and logistics. The 463-ton vehicle requires routine maintenance and is subject to unexpected mechanical failures, given its highly complicated systems. Resolving problems can be challenging and often require the crew to make repairs in space with support from ground teams on Earth. Astronauts aboard the ISS must rely solely on the materials available to them onboard. This requires the support team on Earth to monitor and painstakingly plan for replacement parts and consumables, such as filters and gas, as well as spares like multiplexer-demultiplexer (MDM) data relay boxes, which are a key component of the Command and Data Handling System. The coordination and support necessary for the ISS crew to live and work comfortably in space requires intensive Earth-based mission operations. Ground teams continually monitor the ISS performance, provide necessary vehicle commands, and communicate with the crew. Even before the astronauts leave Earth, the Systems O&M project, in conjunction with the Human Space Flight Operations program, provides the crew training to prepare them for their stay aboard the ISS.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

The ISS program considers all aspects of the mission when developing operations plans to meet program objectives. These include scheduling crew activities, choreographing docking and undocking of visiting crew and supply ships, evaluating supplies of consumables, managing flight plan variability, and resolving stowage issues. The Systems O&M project ensures the ISS is operational and available to perform its research mission at all times.

Because the ISS is an international partnership, program decisions are not made in isolation; they require collaboration with multiple countries to ensure all technical, schedule, and resources supply considerations are taken into account. The experience NASA is gaining through integration with its ISS partners is helping the Agency to better prepare for future partnerships in human space exploration.

A critical component of the Systems O&M project is immediate emergency services and analyses conducted by mission control teams on Earth, known as vehicle and program anomaly resolution. Engineers and operators diagnose system failures and develop solutions, while program specialists respond to changing program needs and priorities through re-planning efforts. These teams ensure appropriate redundancy, training, and procedures are in place to respond to any type of failure at any time. The project requires sparing and repairing of nine highly complex on-orbit systems made up of hundreds of unique Orbital Replacement Units. Additionally, software sustainment manages and executes millions of lines of flight code to support operation and control of the ISS.

Finally, as part of the Administration’s commitment to increase cooperation with industry through the use of public-private partnerships, NASA and NanoRacks signed a Space Act Agreement for an Airlock Module, the first privately funded commercial airlock. The NanoRacks Airlock provides capabilities that will make it useful for a variety of users. It is approximately five times larger than the Japanese Experiment Module (JEM) Airlock so it will provide the capability to robotically transfer larger (or multiple smaller) packages from inside ISS to the external environment for deployment. Additionally, the Airlock provides the interfaces and capability to accommodate both internal and external payloads, including power and Ethernet interfaces.

The implementation of public-private partnerships like this will foster innovation and help prepare the private sector to take a leading role in low Earth orbit during and after the transition off the ISS platform.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

The ISS Systems O&M project continues to maintain resources both on-orbit and on the ground to operate and utilize the ISS. The O&M project maintained success in providing all necessary resources, including power, data, crew time, logistics, and accommodations, to support research while operating safely with a crew of six astronauts. The O&M project supported the arrival and departure of crew and cargo flights to the ISS approximately every three weeks. Each flight required extensive planning and analyses in order to support on-orbit operations, as well as launching, docking, undocking, berthing, unberthing, deorbiting, packing, manifesting, hardware processing, and the on-orbit configuration.

ISS Systems Operations and Maintenance

NASA ground teams continued to monitor overall vehicle health and oversee general maintenance and performance of all the ISS vehicle systems, including command and data handling, communication and tracking, crew health care, environmental control and life support, electrical power, extravehicular activities (EVAs), robotics, flight crew equipment, propulsion, structures and mechanisms, thermal control, guidance, navigation, and control. This past year, one of the ISS multiplexer-demultiplexer (MDM) data relay boxes failed, prompting an expedited, contingency spacewalk by the ISS crew. The MDM is one of two fully redundant systems that controls the functionality of the radiators, solar arrays, cooling loops and other ISS hardware. While this was an unplanned and unexpected spacewalk, the crew rehearses this type of task prior to their mission. Detailed preparation by the ground team, and coordination with the spacewalkers leading up to their task, led to a successful MDM removal and replacement.

The team supported one Russian EVA and six U.S. EVAs in FY 2017. Many of the U.S. EVAs continued the major reconfiguration onboard the ISS which began in FY 2015. NASA is continuing modifications to docking ports to enable traffic flexibility and port redundancy for the U.S. operating segment crew and cargo vehicle missions. Specifically, in the spring of 2017, a total of three EVAs were dedicated to maintenance of the Pressurized Mating Adapter (PMA-3). PMA-3 was robotically removed March 26, 2017, from the Tranquility module and attached to the Harmony module after being prepared during a successful spacewalk on March 24, 2017. A second spacewalk was conducted on March 30, 2017, to finalize the PMA-3 cable connections on Harmony. PMA-3 will receive the International Docking Adapter-3 (IDA) in FY 2019. This is significant as the IDA standardizes the PMAs to allow for efficient transfer of crew, cargo, and power.

The current nickel-hydrogen batteries on the ISS are nearing their end of life and require replacement for ISS life extension. The O&M project will be replacing current nickel-hydrogen batteries with more efficient lithium-ion batteries over several years using multiple EVAs. Astronauts replaced the first three batteries in January 2017. EVAs also supported other maintenance and repairs, including repairs to the Alpha Magnetic Spectrometer (AMS), maintenance to Canadarm2, and inspection of a radiator valve.

Work in Progress in FY 2018

Throughout the year, NASA ground teams will continue to monitor overall vehicle health and oversee general maintenance and performance of all the ISS vehicle systems. The O&M project will continue to manage resource requirements and changes, including vehicle traffic, cargo logistics, stowage, and crew time. In addition to providing anomaly resolution and failure investigation as needed, they plan and provide real-time support for activities, such as EVA and visiting vehicles.

The team plans to support three Russian EVAs and at least nine U.S. EVAs in FY 2018. The first two in the series of spacewalks will focus on necessary robotics maintenance. Robotics activity, controlled by flight controllers on the ground as well as on-board crew, are paramount to ISS operations. Hardware repair/maintenance and visiting vehicle arrival and departure depend upon it. Upcoming maintenance to be performed during the spacewalks includes replacing a Latching End Effector (LEE), which incorporates electronics, sensors, cameras, and primarily latching mechanisms critical to grappling hardware and visiting vehicles. EVAs will also continue to replace aging batteries with more efficient lithium-ion batteries.

ISS Systems Operations and Maintenance

Key Achievements Planned for FY 2019

The ISS O&M project is planning to support the first missions with U.S. astronauts aboard Commercial Crew flights. The ISS program will continue to work closely with the commercial partners to ensure any challenges are addressed and operations and research conducted aboard the ISS continues to be accomplished with minimal issues. NASA plans to work with international partners to maintain a continuous ISS crew member capability by coordinating and managing resources, logistics, systems, and operational procedures. The O&M project will continue to manage resource requirements and changes, including vehicle traffic, cargo logistics, stowage, and crew time. In addition to providing anomaly resolution and failure investigation as needed, they plan and provide real-time support for activities, such as EVA and visiting vehicles.

The team will support three Russian EVAs and at least seven U.S. EVAs in FY 2019. The major reconfiguration activity begun in FY 2015 will be completed with the installation of the second International Docking Adapter. Once completed, the ISS will have two visiting vehicle docking ports and two visiting vehicle berthing ports. While current Commercial Resupply Service vehicles use berthing ports, the new commercial crew vehicles will require docking ports. When a visiting vehicle “docks” to the ISS, that arriving vehicle is in control of attaching itself to the ISS. When a vehicle “berths” to the ISS, the ISS is in control of capturing and attaching the arriving vehicle to the ISS via the Space Station Remote Manipulator System (SSRMS). The process of un-berthing requires the use of the SSRMS which does not support rapid crew evacuations in the event of an emergency. However, berthing ports are bigger and therefore allow for the transfer of larger equipment. EVAs will also continue to replace aging batteries with more efficient lithium-ion batteries.

ISS will begin integration activities for the NanoRacks Airlock Module scheduled for launch in FY 2020. This is the first privately funded commercial airlock and it will increase the capability of transferring equipment, payloads, and deployable satellites. Commercial opportunities through Airlock begin with cubesat and small satellite deployment from station and include a full range of additional services to meet customer needs from NASA and the growing commercial sector. Currently, cubesats and small satellites are deployed through the government-operated Japanese Kibo Airlock. Additionally, the crew on board should be able to assemble payloads typically flown in soft-stowage ISS Cargo Transfer Bags into larger items that currently cannot be handled by the existing Kibo Airlock.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

PROJECT SCHEDULE

The table below provides a schedule for potential EVAs. However, the ISS conducts near-term, real-time assessments of EVA demands along with other program objectives, to efficiently plan all required ISS activities. NASA remains postured to conduct EVAs on short notice in response to specific contingency scenarios. In addition, the ISS program balances routine maintenance EVAs against overall astronaut availability to maintain focus on utilization and research.

Date	Significant Event
Oct 2017	Three U.S. EVAs
Jan 2018	Two U.S. EVAs
Feb 2018	Russian EVA
May 2018	Two U.S. EVAs; Russian EVA
Aug 2018	Russian EVA
Sept 2018	Two U.S. EVAs
Oct 2018	Four contingency U.S. EVSs
Dec 2018	U.S. EVA; Three Russian EVAs
Aug 2019	Six U.S. EVAs

Project Management & Commitments

While NASA maintains the integrator role for the entire ISS, each partner has primary authority for managing and operating the hardware and elements they provide. Within NASA, Johnson Space Center (JSC) in Houston, Texas leads project management of the ISS Systems O&M.

Acquisition Strategy

The current Boeing vehicle sustaining engineering contract extends through September 30, 2020. Requirements of this contract include sustaining engineering of U.S. on-orbit segment hardware and software, technical integration across all of the ISS segments, end-to-end subsystem management for the majority of the ISS subsystems and specialty engineering disciplines, and U.S. on-orbit segment and integrated system certification of flight readiness.

ISS Systems Operations and Maintenance

Major Contracts/Awards

Element	Vendor	Location (of work performance)
U.S. on-orbit segment Sustaining Engineering Contract	The Boeing Company	JSC

Independent Reviews

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Advisory Council	Dec 2017	Provides independent guidance for the NASA Administrator	No new formal recommendations or findings	2018
Other	NASA Aerospace Safety Advisory Panel	Oct 2017	Provides independent assessments of safety to the NASA Administrator	No new formal recommendations or findings	2018

ISS RESEARCH

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**347.3**	**--**	**356.7**	**347.7**	**365.6**	**360.6**	**345.6**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

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On May 2, 2017, Commander Peggy Whitson works on the OsteoOmics bone cell study utilizing the Microgravity Science Glovebox in the U.S. Destiny laboratory. This could lead to better preventative care or therapeutic treatments for people suffering bone loss as a result of bone diseases like osteopenia and osteoporosis, or for patients on prolonged bed rest.

The International Space Station (ISS) is an orbiting platform that provides the only current capability for human-assisted space-based research and a unique venue for developing technologies for future human spaceflight exploration. ISS enables scientific investigation of physical, chemical, and biological processes in an environment very different from Earth. As a research and development facility, ISS supports a variety of science laboratories, external testbeds, and observatory sites, allowing astronauts to conduct a wide range of experiments in low Earth orbit (LEO). ISS is managed as a U.S. National Laboratory (National Lab), enabling use of its research facilities by the scientific community, the private sector and other Government agencies to benefit the U.S. economy. ISS supports research across a diverse array of disciplines, from fundamental physics and biophysics to human physiology and biotechnology. ISS is the primary science platform for the Open Science Initiatives GeneLab and Physical Sciences Informatics, which enable next generation research by creating publicly available open access data resources. In addition, ISS supports educational activities that engage the public in the national and global endeavor of human spaceflight, and inspire students to excel in science, technology, engineering, and mathematics.

ISS is a collaborative venture with our international partners, including the Canadian, European, Japanese, and Russian space agencies. Although each partner has distinct national goals for ISS research, all participating agencies share a unified goal to extend the resulting knowledge for future exploration and to benefit humanity. Within NASA, mission directorates prioritize their research investments based on Exploration roadmaps for technologies needed to support future exploration and recommendations from the National Academies, such as the Decadal Survey on Biological and Physical Sciences in Space.

ISS RESEARCH

The ISS Research program funds fundamental and applied research in biological and physical sciences to enable future human exploration and pioneer scientific discover in low Earth orbit. It also funds a multi-user systems support (MUSS) activities, which provides strategic, tactical, and operational support to all NASA sponsored and non-NASA sponsored payloads (including those of the international partners), as well as operation of on-orbit research facilities. MUSS includes the development of new capabilities and technologies for ISS. ISS Research also supports the Center for the Advancement of Science in Space (CASIS), a non-profit organization that manages the ISS National Lab.

Research and development conducted aboard ISS, sponsored by both NASA and the Agency's commercial partners, holds the promise of next-generation technologies in health and medicine; robotics, manufacturing, and propulsion; and development of applications that will benefit life on Earth. As NASA’s only current long-duration crewed orbital testbed, the ISS is used by researchers to study the effects of long-duration exposure to the space environment on the crew and devise and test countermeasures to offset health risks. Additionally, researchers evaluate the extended performance of equipment critical to long-duration flight by testing the hardware’s ability to survive in the space environment, determining life-limiting issues and repair capabilities, and evaluating upgrades to improve performance.

The mission of the ISS U.S. National Lab is to foster scientific discovery and technological innovation in space, expand U.S. leadership in commercial space, and inspire the next generation. CASIS, a non-profit institution, selects and manages ISS National Lab R&D projects that satisfy this mission. The objective of these projects is to provide value and impact back to the U.S. taxpayer, ultimately driving new market creation by building demand, enabling supply, and facilitating investment. CASIS engages a variety of new-to-space users, whose projects are in the fields of life science, physical science, technology development, and remote sensing. Over the last five years, CASIS has transitioned from a traditional grant-based model to a value-based model, engaging Government agencies, academic institutions, and the private sector to solve cross-cutting problems on the ISS and leverage private and public sector funding.

At the conclusion of Expedition 52 in September 2017, more than 101 countries around the world have performed over 2,430 research investigations utilizing ISS with more than 3,400 investigators. In addition, over 1,600 R&D results have been published in scientific journals and magazines (Note: these are early estimates. Final numbers are expected to publish in early 2018).

COMMERCIALIZATION ACTIVITIES ON ISS

NASA and the ISS program, in partnership with CASIS, are leveraging ISS to enable the commercialization of low Earth orbit. Low Earth orbit is already partially commercialized – private sector companies operate numerous robotic spacecraft in this region of space, and the NASA Crew and Cargo program purchases commercial transportation services to and from low Earth orbit. However, ISS is playing a unique role in advancing the frontiers of economic activity in space. NASA is creating public-private partnerships which will allow entrepreneurs to explore potential revenue-generating activities enabled by the unique microgravity environment. By developing concepts and technologies that can generate revenue in low Earth orbit, these public-private partnerships will foster innovation and help prepare the private sector to take a leading role in low Earth orbit. In addition, NASA is advancing the research capabilities and analytical tools onboard the ISS by purchasing services from commercial entities that own and operate these capabilities, rather than follow the traditional government-contractor

ISS RESEARCH

relationship to acquire NASA-owned facilities that have been used in the past. Through these activities, in conjunction with the Commercial LEO Development program, NASA is expanding demand and laying the foundation for future commercial options, such as the use of commercial orbital platform(s), that can meet the Agency's research and technology development requirements beyond ISS.

NASA and its partners have different responsibilities within the broader commercialization effort. CASIS is reaching broad sectors of traditional and non-traditional commercial companies, as well as other Government agencies to utilize the ISS National Lab and stimulate demand for ongoing commercial activity in low Earth orbit. NASA is actively implementing new, streamlined processes for researchers through Revolutionize ISS for Science and Exploration (RISE), which enables users to fly research more quickly and cost effectively. In FY 2017, NASA awarded payload integration service contracts, entitled Research, Engineering, Mission and Integration Services (REMIS) to 14 commercial companies. These awards transition previous NASA-only functions to a variety of commercial vendors, thus increasing the opportunity for the commercialization of low Earth orbit. Feedback received from the request for information (RFI) for Advancing Economic Development in low Earth orbit via Commercial Use of Limited Availability, and Unique International Space Station Capabilities will now be addressed through the newly-created Commercial LEO Development program.

New external and internal commercial research platforms have launched or plan to launch in the next two years. The Materials on ISS Experiment-Flight Facility (MISSE-FF), developed by Alpha Space, and the Multi-User System for Earth Sensing (MUSES), developed by Teledyne Brown Engineering, will significantly augment ISS accommodations for external research. The BioChip SpaceLab, developed by Hnu Photonics, the BioBox, developed by Science, Technology and Advanced Research Systems (STaARS), and the Tango Lab, developed by Space Tango, will bring online new commercially-operated internal capabilities for space biology research. The BioChip SpaceLab facility will provide a portable, remote-controlled, automated microfluidics platform for general biological investigations and planned stem cell research. Ownership of all of these platforms is retained by their respective developers. Each developer is actively marketing the platform and seeking to increase the commercial user base of the ISS.

EXPLANATION OF MAJOR CHANGES IN FY 2019

Work supporting Commercial LEO Development was transferred to that new program.

ACHIEVEMENTS IN FY 2017

ISS NATIONAL LAB AND COMMERCIAL ACTIVITIES

Satellites are powered by solar arrays, which convert sunlight into energy. The Roll-Out Solar Array (ROSA) flight experiment tested an entirely new deployable solar array design that is stronger, lighter, and packaged more compactly for launch. ROSA's improved power density over existing technology and can be easily adapted to different sizes, making it a promising material for use on future NASA, military and commercial solar-powered spacecraft.

The Space Test Program Houston-5 platform hosted a wide variety of experiments. These included the Lightning Imaging System (LIS) which measures the amount, rate and energy of lightning as it strikes around the world. Understanding the processes that cause lightning and the connections between lightning and subsequent severe weather events is a key to improving weather predictions and saving life and property. From the vantage of ISS, the LIS instrument observes lightning over a wider geographical area than previous sensors. The platform also hosted Raven, a real-time spacecraft navigation system that provides the eyes and intelligence to see a target and steer toward it safely. Future robotic spacecraft will need advanced autopilot systems to help them safely navigate and rendezvous with other objects, as they will be operating thousands of miles from Earth.

Only a few animals, such as tadpoles and salamanders, can regrow a lost limb, but the onset of this process exists in all vertebrates. Rodent Research-4, sponsored by the U.S. Department of Defense (DoD) and CASIS, studied tissue regeneration and wound healing responses, and how microgravity conditions impact this process. When analysis of the results is completed, the results will provide a new understanding of the biological processes involved in wound healing and tissue regeneration as well as potentially could provide information on conditions such as osteoporosis. In addition, this research has the potential to lead to new treatment options for the more than 30 percent of the patient population who do not respond to current options for treating chronic non-healing wounds. Rodent Research-5 continued bone loss experimentation and tested a new drug that can both rebuild and block bone loss on mice experiencing spaceflight-induced skeletal damage. Because osteoporosis affects more than 200 million people worldwide, this research has the potential to result in new innovative treatments that promote bone formation to improve health for crew members in orbit and people on Earth.

Other CASIS-sponsored experiments included one on the growth and differentiation of human stem cells in microgravity which analyzed gene expression profiles of cells grown on the ISS to provide insight into how human cancers start and spread. This could aid in the development of prevention and treatment plans. A Merck Research Labs investigation crystallized a human monoclonal antibody currently undergoing clinical trials. With the absence of gravity and convection aboard ISS, crystals can be grown much larger and with more pure compositions and structures than on Earth. Results have the potential to improve drug delivery and manufacturing on Earth.

During FY 2017, the ISS National Lab set new records for R&D payload upmass and utilization: 76 payloads were launched to the ISS (a 31% increase over FY 2016), carrying more than 100 individual experiments. Payloads included ongoing projects from Fortune 500 customers Merck, Eli Lilly & Co., and Procter & Gamble, as well as notable new payloads from the nonprofit Michael J. Fox Foundation and Fortune 100 company Hewlett Packard Enterprise. There were multiple payloads in collaboration with the DoD and Oak Ridge National Laboratory. The ISS National Lab additionally selected 44 new projects in for future flight, 75 percent of which were new to space and more than half of which were from the private sector, including Anheuser-Busch (plant research), Goodyear (materials research), AstraZeneca-MedImmune (drug delivery), and Sanofi Pasteur (vaccine design). Eight of the FY 2017 selected projects are funded by NSF or NIH in collaboration with CASIS. In total, CASIS-selected projects to date have leveraged more than $100 million in non-CASIS, non-NASA funding.

As of the end of FY 2017, CASIS long term estimates on the projected value and impact of the total CASIS-selected R&D project portfolio included (1) incremental revenues of approximately $900 million, (2) average time-to-market acceleration of 1–3 years, (3) estimated addressable markets of $110 billion, (4) addition of approximately 400 direct jobs (with broader supply chain impact), and (5) more than 20 new solution pathways (a measure of innovation that can lead to a major advance in knowledge or new intellectual property). Fifteen new peer-reviewed journal articles were published this year detailing R&D

ISS RESEARCH

sponsored by CASIS and the ISS National Lab, adding to the total of more than 1,400 peer-reviewed publications resulting from the ISS. Finally, seven companies are currently operating eleven commercial R&D facilities onboard the ISS, four of which were launched in FY 2017.

NASA ACTIVITIES

The Cool Flames experiment used the Combustion Integrated Rack to help scientists develop models which may lead to more efficient advanced engines and new fuels for use in space and on Earth by studying a mode of combustion that occurs at a much lower temperature and which can be difficult to sustain. Cool Flames is one of the first ISS experiments that will share all of the data to the "open source" Physical Sciences Informatics database for public users to conduct additional independent research.

The Lighting Effects investigation is testing a new lighting system aboard the station designed to enhance crew health, alertness and performance in addition to keeping their body clocks in proper sync with the ISS working and resting schedule. The system uses adjustable light-emitting diodes (LEDs) and a Dynamic Lighting Schedule that varies intensity and spectrum of the LEDs in tune with sleep and wake schedules. Lighting manipulation has potential as a safe, non-pharmacological way to optimize sleep and circadian regulation on space missions. People on Earth, especially those who work night shifts, could also benefit from this study as the results could help improve alertness and sleep by adjusting lighting for intensity and wavelength.

The Advanced Plant Habitat (APH) is a large growth volume habitat that has been specifically designed for multi-generational and developmental studies of plant research in microgravity. The APH is the largest enclosed environmentally controlled chamber designed to support commercial and fundamental plant research onboard ISS. The APH facility will enable NASA to understand how to build exploration bio-regenerative life support systems with closed system ecology, mass, power, shelf life, and storage volume. This research will also enable NASA to produce healthy food, waste management, and biological stability of the habitat, which is critical knowledge for long-term operations of future exploration systems.

Outside the Earth’s magnetic field, astronauts are exposed to space radiation that can reduce the body's immune response, and increase cancer risk. Radiation also interferes with onboard electronics. The Fast Neutron Spectrometer investigation helps scientists understand and monitor high-energy neutrons, part of the radiation exposure experienced by crews during spaceflight, by studying a new technique to measure electrically neutral neutron particles. Because it experiences radiation from a variety of sources, ISS provides an excellent environment for evaluating this instrument. This improved measurement will help protect crews on future exploration missions.

The Science Mission Directorate-sponsored SAGE III Earth observation instrument records changes to the Earth's ozone layer, such as fluctuations in concentrations of greenhouse gases and thinning of the ozone layer. Scientists do not yet understand how these changes affect climate, and accurate long-term measurements such as those provided by SAGE III are crucial for understanding the processes that impact climate change.

ISS RESEARCH

WORK IN PROGRESS IN FY 2018

ISS NATIONAL LAB AND COMMERCIAL ACTIVITIES

New accommodations aboard ISS will continue to provide valuable opportunities for the commercial sector from both a research and technology development perspective but also as a commercial service provider. A Zero-G Mass Measurement Device, developed by Orbitec; the Advanced Space Experiment Processor (ADSEP) and Multi-specimen, Variable-gravity Platform (MVP), developed by Techshot; and the DLR Earth Sensing Instrument Spectrometer (DESIS-30), a hyperspectral instrument jointly developed by DLR and Teledyne Brown Engineering, will continue to augment research capabilities as well as commercial participation. Next generation laboratory capabilities will also launch, including an advanced microscopy suite and a new rapid freeze capability for biological specimens.

The CASIS-sponsored Fiber Optics Manufacturing in Space demonstrates the merits of manufacturing fiber optic filaments in microgravity. The optical fiber chosen for production aboard the ISS is a high value optical fiber, which is known as ZBLAN. While ZBLAN has potential to far exceed the performance of other fibers in common use, when terrestrially produced the fiber suffers from glass impurities and microcrystal formation which reduce performance. Microgravity has been shown to significantly reduce these imperfections, and so the production of fibers in space may enable not only improved materials but also a new frontier in manufacturing and space utilization.

The CASIS-sponsored Rodent Research-6 will test an implantable drug delivery system that circumvents the need for daily injections. If successful, this system could serve as a universal technology for drug delivery and animal testing. In collaboration with Novartis and NanoMedical Systems, this validated system may rapidly translate into a commercial product.

The ISS National Lab will continue to seek high-value multi-year and multi-institutional projects that leverage external funding, including expansion of relationships with non-NASA government agencies. A $1 million sponsored funding partnership is underway with Target Corporation focused on achieving cotton sustainability, and two new joint solicitations with NIH and NSF are expected for FY 2018 release. Private sector payloads planned for launch include projects from Novartis, Honeywell, Delta Faucet, Nemak, Anheuser-Busch, and Nalco Champion, and new commercially operated facilities planned for launch include a bioculture system, optical fiber fabrication equipment, and a new multipurpose variable-gravity platform (centrifuge). These new facilities have been identified as needed by current and future ISS customers in the private and academic sectors. More than 42 million students have participated in ISS programs to date, enhancing future STEM expertise, which is essential for U.S. competitiveness and leadership. The ISS National Lab will continue to support STEM programs, educational partnerships, and outreach initiatives, with a goal of reaching 700,000 U.S. students in FY 2018.

NASA ACTIVITIES

NASA will continue to enhance the existing open science pipeline to study gravity as a continuum by utilizing ground-based and on-orbit ISS research. The GeneLab Phase 2 Data System will go live in 2018 increasing the ability of scientists to conduct data analysis and create next-generation hypotheses about the effects of microgravity on living organisms. The Life Beyond low Earth orbit science initiative will seek to investigate biological systems in habitats beyond low Earth orbit. In conjunction with other ISS flight experiments, researchers will be able to explore the differences between biological adaptation and response in low Earth orbit on ISS to those changes observed in the deep space environment.

The Cold Atom Laboratory will take advantage of the microgravity environment to create the coldest known matter in the universe—just trillionths of a degree above absolute zero. The laboratory could enable significant discoveries in atomic physics, which could apply to next generation communications, navigation, timekeeping, and computing systems.

Sponsored by the Science Mission Directorate, the Total and Spectral Solar Irradiance Sensor will provide absolute measurements of the total solar irradiance and spectral solar irradiance, which is important for accurate scientific models of climate change and solar variability.

The Robotic Refueling Mission 3 technology demonstration will test in-space rocket propellant transfer technology. It will demonstrate the ability to transfer and freeze a cryogenic fluid and transfer methane gas, both in zero-gravity. These new technologies, tools, and techniques could eventually give satellite owners resources to diagnose problems on orbit, fix anomalies, and keep certain spacecraft instruments performing longer in space.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

The FY 2019 research plan on ISS is still in development. Some key highlights of upcoming investigations already in work for FY 2019 are the National Lab external payloads Space Test Program (STP)-Houston 6, STP-Sat-4 and the NASA payload GEDI. In addition, NASA will continue to conduct rodent research studies to better understand the effects of long term microgravity exposure on humans and the Cold Atom Lab will continue science operations.

DoD's STP-Houston 6 external experiment pallet is comprised of multiple individual payloads and includes a demonstration of X-ray optical communications. STP-Sat-4 is a free flying spacecraft to be deployed from ISS carrying multiple experiments.

The Global Ecosystem Dynamics Investigation (GEDI) will produce the first high resolution laser ranging observations of the 3D structure of Earth. The GEDI system uses three lasers which fire 242 times per second, covering 25 meters and generates the 3D image. The precise measurements of forest canopy height, canopy vertical structure, and surface elevation will greatly advance our ability to characterize important carbon and water cycling processes, and biodiversity and habitat. This data will be of great value for weather forecasting, forest management, glacier and snowpack monitoring, and generation of more accurate digital elevation models.

NASA will award research grants utilizing the Physical Sciences Informatics (PSI) data repository to enable new discoveries with data acquired on ISS. In fulfillment of the new Open Science model, the PSI system is accessible and open to the public world-wide. This provides the opportunity for researchers to data mine results from prior flight investigations, expanding on the research performed. This approach will allow numerous ground-based investigations to be conducted from one flight experiment's data, exponentially increasing our body of knowledge within the biophysics, combustion science, fluid physics, complex fluids, fundamental physics, and materials science fields.

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CASIS will continue to leverage private sector, non-NASA, and investment capital, with a goal of reaching $150 million in FY 2019 in cumulative total sponsored research, a 50 percent increase in two years. The ISS National Lab will also continue development of R&D programs to further enable economic development of the lowEarth orbit platform market, continuing its focus on highly innovative programs with high-impact potential to enable specific markets. Payloads currently scheduled for launch include additional projects from the private sector, academia, and non-NASA Government agencies, as well as two new commercially operated research facilities. The NanoRacks Airlock Module, the first privately-funded commercial airlock, is also expected to launch in FY 2019 and should triple the number of small satellites that can be deployed at one time. Finally, the ISS National Lab portfolio will continue to partner with established STEM organizations to support complementary educational initiatives, with a goal of reaching one million U.S. students in FY 2019.

Project Schedule

An increment is a period of time for ISS operations that spans from one Soyuz undock to the next Soyuz undock. There are four increments per year that consist of cargo ship arrivals and departures, as well as activities performed on-board, including the research performed. The table below outlines start dates of the upcoming increments to ISS.

Date	Significant Event
Sep 2017	Increment 53
Dec 2017	Increment 54
Feb 2018	Increment 55
Jun 2018	Increment 56
Aug 2018	Increment 57
Oct 2018	Increment 58
Feb 2019	Increment 59s
May 2019	Increment 60
Sep 2019	Increment 61

Project Management & Commitments

The Space, Life, and Physical Sciences Research and Applications Division at NASA Headquarters manages Biological and Physical Sciences (BPS) research. The division, working closely with the Office of the Chief Scientist, establishes the overall direction and scope, budget, and resource allocation for the project, which the NASA Centers implement. The ISS program office is the interface with CASIS and manages other ISS Research activities such as MUSS and National Lab enabling activities.

ISS RESEARCH

Element	Description	Provider Details	Change from Formulation Agreement
Biological and Physical Sciences	This element includes all NASA-sponsored biological and physical research.	Provider: NASA Centers, contractors, and principal investigators Lead Center: Headquarters (HQ) Performing Center(s): Ames Research Center (ARC), Glenn Research Center (GRC), Jet Propulsion Laboratory (JPL), Marshall Space Flight Center (MSFC), Kennedy Space Center (KSC) Cost Share Partner(s): N/A	N/A
MUSS (includes National Lab activities)	MUSS activities support all research on ISS, both NASA sponsored and non-NASA sponsored.	Provider: ISS program and contractors Lead Center: JSC Performing Center(s): MSFC, ARC, GRC, KSC, JPL Cost Share Partner(s): N/A	N/A

Acquisition Strategy

NASA awards contracts and grants for conducting research on ISS. NASA prioritizes ISS research based on recommendations from the National Academies and the Decadal Survey on BPS in Space. NASA selected CASIS to manage non-NASA ISS Research activities. This independent non-profit will further develop national uses of ISS.

Peer review is the means to ensure a high-quality research program. Engaging leading members of the research community to assess the competitive merits of submitted proposals is essential to ensuring the productivity and quality of ISS Research. Biological and Physical Sciences research uses both traditional and open science NASA Research Announcements to provide researchers, selected by peer-review, the opportunity to develop complete flight experiments and allow universities to participate in flight and ground research involving their scientists. CASIS also conducts independent reviews of science merit and economic valuation in selecting experiments for use of the ISS as a National Lab.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Vehicle Sustaining Engineering Contract	The Boeing Company	Houston, TX
Huntsville Operations Support Center	COLSA Corporation	Huntsville, AL

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Element	Vendor	Location (of work performance)
Mission Operations and Integration (MO&I) Contract	Teledyne Brown Engineering	Huntsville, AL
ISS National Lab Management Entity	CASIS	Melbourne, FL

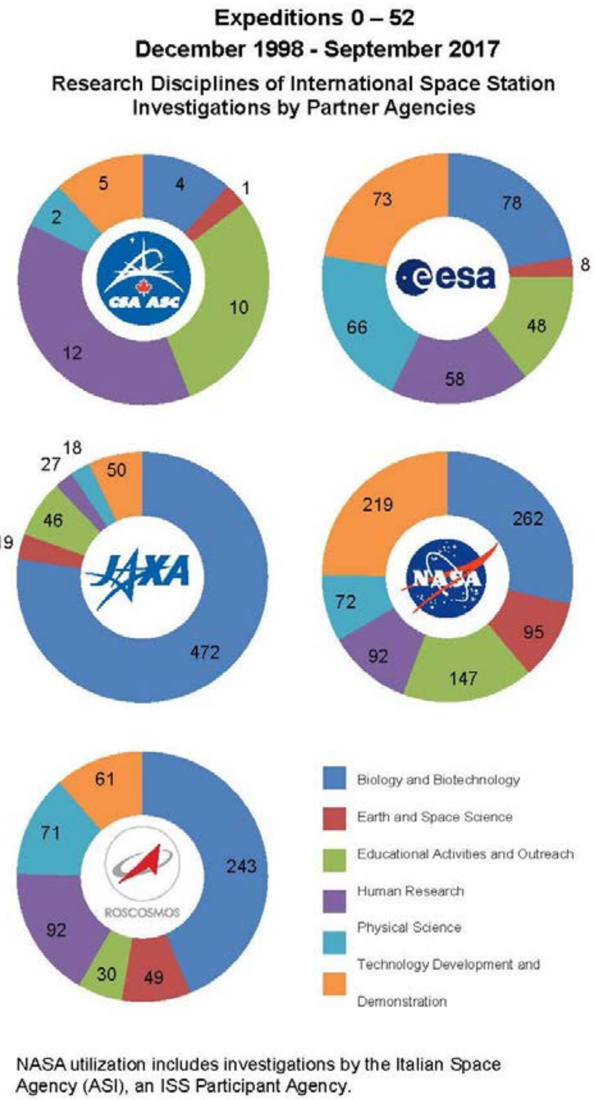
INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Advisory Council	Dec 2017	Provides independent guidance for NASA Administrator	No new formal recommendations or findings for ISS	2018
Other	NASA Aerospace Safety Advisory Panel	Oct 2017	Provides independent assessments of safety to the NASA Administrator	No new formal recommendations or findings for ISS	2018
Other	National Academy of Science	Jan 2018	Review progress on 2011 Decadal Survey for life and physical sciences research and recommend adjustments to BPS portfolio	Several findings and recommendations for HEO to increase the scientific productivity of ISS research	2021

HISTORICAL PERFORMANCE

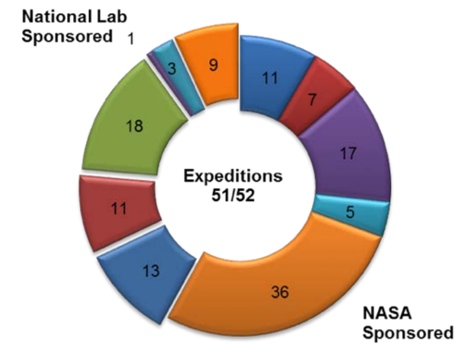
In FY 2017, NASA estimates ISS partners performed 488 research and technology investigations, including 244 new investigations. During this period, NASA estimates that NASA performed 174 investigations, including 123 new investigations. The charts below display historical data, by partner agency, for research investigations performed on ISS since 1998, and a comparison of FY 2017 NASA-sponsored and National Lab-sponsored investigations.

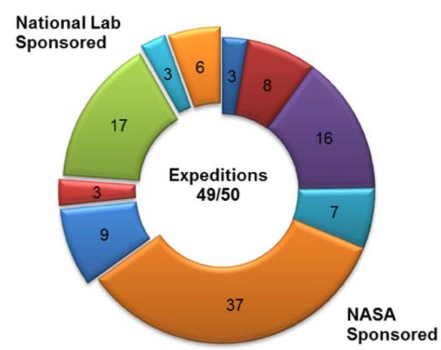
ISS RESEARCH



Expeditions 49-52

NASA vs. National Lab Sponsored





SPACE TRANSPORTATION

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Crew and Cargo Program	1404.2	--	**1935.6**	1793.2	1822.6	1792.8	1771.0
Commercial Crew Program	1184.8	--	**173.1**	35.8	36.3	36.3	36.3
Total Budget	**2589.0**	**--**	**2108.7**	**1829.1**	**1858.9**	**1829.2**	**1807.3**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

The SpaceX Falcon 9 rocket, with the Dragon spacecraft onboard, launches from pad 39A at NASA's Kennedy Space Center in Cape Canaveral, Florida (June 3, 2017). Dragon is carrying almost 6,000 pounds of science research, crew supplies and hardware to ISS. This was the 100th launch, and sixth SpaceX launch, from this pad. Previous launches include 11 Apollo flights, the launch of the unmanned Skylab in 1973, 82 shuttle flights and five SpaceX launches.

The Space Transportation theme's objective is to transport U.S. astronauts and cargo safely back and forth to space, including America's national laboratory in low Earth orbit, the International Space Station (ISS). This theme includes the Commercial Crew Program (CCP) and the Crew and Cargo Program. Maintaining ISS requires a fleet of vehicles and launch locations to transport astronauts, science experiments, critical supplies, and maintenance hardware; replenish propellant; and dispose of waste.

CCP partners with the U.S. commercial sector to develop and operate safe, reliable, and affordable crew transportation to low Earth orbit. NASA awarded Commercial Crew Transportation Capability (CCtCap) contracts to Boeing and SpaceX in September 2014. Through its certification efforts, NASA will ensure the selected commercial transportation systems meet NASA's safety and performance requirements for transporting crew to ISS.

Within the Crew and Cargo Program, NASA purchases cargo transportation to ISS under Commercial Resupply Services (CRS) contracts with Orbital ATK, Sierra Nevada, and SpaceX. NASA purchases crew transportation to ISS from the Russian Roscosmos State Corporation, known as Roscosmos, and from commercial providers, Boeing and SpaceX. The budget also supports related activities, such as integration work required to ensure that these visiting vehicles can safely dock or berth to ISS and hardware like the NASA docking system.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

CREW AND CARGO PROGRAM

Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**1404.2**	**--**	**1935.6**	**1793.2**	**1822.6**	**1792.8**	**1771.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

The Orbital ATK Antares rocket, with the Cygnus spacecraft onboard, is raised into the vertical position on launch Pad-0A at NASA's Wallops Flight Facility in Virginia (November 9, 2017). Orbital ATK’s eighth contracted cargo resupply mission with NASA delivered over 7,400 pounds of science and research, crew supplies and vehicle hardware to ISS.

Maintaining the International Space Station (ISS) requires a fleet of launch vehicles to sustain a constant supply line of both crew and cargo that is crucial to ISS operations and research. Deliveries not only provide science experiments, critical supplies and maintenance hardware, but also rotate crewmembers, return critical research and equipment for repair, and dispose of waste.

The Crew and Cargo program manages transportation services provided by both international partners and domestic commercial providers. NASA’s commercial service contracts to resupply the ISS have changed the way the Agency does business in low Earth orbit. With these contracts, NASA continues to advance commercial spaceflight, while supporting the American jobs created by this industry.

NASA purchases cargo delivery to the ISS under the original Commercial Resupply Services (CRS) contracts with Orbital ATK and SpaceX. Orbital ATK, SpaceX, and Sierra Nevada have also begun work under the follow-on CRS-2 contracts for missions beginning in 2019. For CRS flights to ISS, SpaceX currently and Sierra Nevada will in the future launch CRS missions from Cape Canaveral, Florida. Both of these providers have or will have the capability to return science experiments to Earth. SpaceX uses their Falcon 9 rocket to launch their Dragon cargo vehicle, while Sierra Nevada will be using the Atlas V rocket to launch their Dream Chaser cargo vehicle. Orbital ATK primarily launches their Cygnus cargo module on their Antares rocket from the Mid-Atlantic Regional Spaceport at NASA's Wallops Flight Facility (WFF) in Virginia. However, Orbital ATK has also launched CRS missions on Atlas V rockets from Cape Canaveral, Florida. Orbital ATK provides trash disposal and conducts additional experiments before the Cygnus spacecraft burns up in the atmosphere after leaving ISS. The Crew and Cargo budget

CREW AND CARGO PROGRAM

Formulation	Development	Operations

supports all milestone payments for these contracted flights to provide for cargo transportation, including transportation for National Laboratory science research payloads.

The CRS contract vehicle is among NASA's most successful public-private partnerships. NASA used a series of fixed-price, milestone-based Space Act Agreements to support the development of several companies' efforts to develop commercial cargo resupply capabilities. As a result, NASA is now able to purchase these commercial services from several providers using fixed-price contracts, which has yielded a cost savings for the Federal Government. The results of this arrangement have been a reinvigorated U.S. space launch industry, redundancy in the cargo resupply mission area that has increased mission assurance, and robust private sector employment. NASA is leveraging these lessons learned both in this program to improve the CRS-2 contract vehicle and in other programs to expand the successful use of public-private partnerships.

Crew transportation is currently provided using the Russian Soyuz vehicle. NASA will continue to use Soyuz for crew transportation until a domestic capability is available. NASA has purchased Soyuz crew transportation services through both the Russian Roscosmos State Corporation, known as Roscosmos, and through Boeing.

The Commercial Crew Program (CCP) manages the Commercial Crew transportation Capability (CCtCap) contracts with Boeing and SpaceX to develop and provide domestic crew transportation to the ISS. CCP is funding the initial post certification missions (i.e., crew missions) to the ISS; subsequent missions are funded by the Crew and Cargo Program. The first post certification missions to ISS are scheduled for FY 2019.

The Crew and Cargo Program also funds activities supporting visiting vehicles that provide transportation for the ISS, including integration activities and the NASA docking system.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

Orbital ATK (OA) completed six CRS milestones in support of seven commercial resupply flights, including milestones for successful completion of two flights in FY 2017. Their OA-5 flight was the first flight of the upgraded Antares rocket, which provides an increase in cargo upmass capability. SpaceX (SpX) completed 16 CRS milestones in support of 10 commercial resupply flights, including milestones for the successful completion of three flights in FY 2017. The SpX-11 mission was the first re-use of a Dragon spacecraft capsule. Under CRS-2, Sierra Nevada and SpaceX have also successfully completed milestones through their Preliminary Design Reviews, while Orbital ATK has completed milestones through their Critical Design Review. The program funded CCtCap contract milestones for crew missions subsequent to the initial post certification missions that will be flown by Boeing and SpaceX. More information on CCtCap progress can be found under the CCP portion of this document.

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Starting in March of 2017, Roscosmos reduced their crew size on the Russian segment from three to two cosmonauts until late FY 2018. This provided an opportunity to purchase additional Soyuz crew transportation in order to increase research capability on the ISS. Boeing acquired the rights to these vacant seats, which were then procured by NASA from Boeing. In September of 2017, Soyuz 52S carried an additional U.S. operating segment (USOS) astronaut increasing the USOS crewmembers on ISS from three to four. In total the program supported five Soyuz launches. The program also supported three Progress launches (Russian cargo vehicle) and one HTV (Japanese cargo vehicle) launch that are not funded by NASA.

WORK IN PROGRESS IN FY 2018

NASA expects five commercial resupply flights to deliver research and logistics hardware in FY 2018. Orbital ATK plans to launch two CRS flights and complete seven milestones in support of six commercial resupply flights. SpaceX plans to launch three CRS flights and complete 17 performance milestones in support of ten commercial resupply flights. Orbital ATK, Sierra Nevada, and SpaceX will continue to perform CRS-2 integration milestones with plans to complete a total of five milestones collectively. Sierra Nevada completed its vehicle drop test which solidified several design aspects for its CRS-2 vehicle as they proceed to Critical Design Review. The program will also continue funding CCtCap contract milestones for crew missions with Boeing and SpaceX.

The ISS will continue with the USOS crew increased to four until August 2018. The program will support four Soyuz launches. The program will also support three Progress launches and one HTV launch that are not funded by NASA.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

The Crew and Cargo program will enable continued research and technology development by providing a stable crew and cargo flight plan. To ensure a stable crew plan, NASA exercised an option with Boeing which provides Soyuz crew transportation services for three USOS crew members in 2019. Currently, domestic crew capability is scheduled to become available in April 2019 for SpaceX and in May 2019 for Boeing. Once U.S. commercial crew launch services become available, NASA will be able to permanently increase the crew size on the USOS from three astronauts to four astronauts. On average, this will double the total number of hours of crew time allocated to perform research on board ISS each week.

NASA expects five commercial resupply flights to deliver research and logistics hardware in FY 2019. Orbital ATK plans to launch two commercial resupply flights and complete nine performance milestones in support of six CRS/CRS-2 flights. SpaceX plans to launch three commercial resupply flights and complete 16 performance milestones in support of nine CRS/CRS-2 flights. Sierra Nevada plans to complete three performance milestones in support of two CRS-2 flights. These resupply flights will be vital for delivering not only the critical "day to day" supplies needed, but also the experiments and investigations that will enable the astronauts to continue important research on ISS. They will also support the increased research enabled by the additional astronaut once commercial crew is available. Orbital ATK and SpaceX will complete CRS-2 integration milestones in FY 2019. Sierra Nevada will follow with completion in FY 2020. NASA is planning for the first CRS-2 flight in late 2019 (FY 2020).

Formulation	Development	Operations

The flight schedule also includes three Progress launches and one HTV launch that are not funded by NASA.

Project Schedule

Maintaining a regular rate of cargo delivery on a mix of NASA and partner vehicles ensures the ISS can sustain nominal operations and maintenance, while allowing the program to respond to any anomalies that might occur. The table below shows scheduled ISS flight plans for FY 2018 and FY 2019. NASA funds SpaceX and Orbital ATK cargo missions, Boeing and SpaceX crew missions, as well as Soyuz seats related to USOS crew requirements. The planned spacing of the Soyuz crew rotation flights ensures a continuous crew presence on the ISS, and smooth transitions between crews.

Date	Significant Event
Oct 2017	Progress 68P
Nov 2017	OA-8
Dec 2017	SpX-13
Dec 2017	Soyuz 53S
Feb 2018	Progress 69P
Mar 2018	Soyuz 54S
Apr 2018	SpX-14
May 2018	OA-9
Jun 2018	SpX-15
Jun 2018	Soyuz 55S
Jul 2018	Progress 70P
Aug 2018	HTV-7
Sep 2018	Soyuz 56S
Oct 2018	Progress 71P
Nov 2018	Soyuz 57S
Nov 2018	OA-10
Nov 2018	SpX-16
Dec 2018	3R (Russian Proton launch of Multipurpose Laboratory Module)

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Date	Significant Event
Feb 2019	SpX-17
Feb 2019	Progress 72P
Mar 2019	Soyuz 58S
Apr 2019	Progress 73P
Apr 2019	OA-11
Apr 2019	U.S. Crew Vehicle (USCV)-1
May 2019	U.S. Crew Vehicle (USCV)-2
May 2019	Soyuz 59S
May 2019	SpX-18
Jun 2019	6R (Soyuz launch of Russian Node Module)
Jul 2019	HTV-8
Aug 2019	U.S. Crew Vehicle (USCV)-3
Aug 2019	U.S. Crew Vehicle (USCV)-4
Aug 2019	Progress 74P
Sep 2019	Soyuz 60S

Project Management & Commitments

JSC is responsible for management of the Crew and Cargo Program.

Element	Description	Provider Details	Change from Formulation Agreement
Crew transportation	Until a domestic capability is available, Soyuz will be used for crew transportation to ISS either though Roscosmos or Boeing. Once available, commercial crew transportation will be provided by Boeing and SpaceX.	Provider: Roscosmos; Boeing Lead Center: JSC Performing Center(s): N/A Cost Share Partner(s): Canadian Space Agency (CSA), European Space Agency (ESA), and JAXA	N/A

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Cargo transportation	Orbital ATK, SpaceX, and Sierra Nevada will provide cargo transportation to the ISS via the major contracts described below. JAXA will provide additional cargo transportation as part of the ISS partnership. Roscosmos will also provide nominal cargo transportation via Soyuz purchased for crew transportation.	Provider: Orbital ATK, SpaceX, Sierra Nevada, JAXA, and Roscosmos Lead Center: JSC Performing Center(s): Goddard Space Flight Center (GSFC), KSC Cost Share Partner(s): CSA, ESA, and JAXA	N/A

Acquisition Strategy

The ISS program competitively procures all ISS cargo transportation services, excluding services obtained via barter with our international partners or nominal cargo transportation provided by Soyuz. On January 14, 2016, NASA competitively awarded CRS-2 contracts to Orbital ATK, Sierra Nevada, and SpaceX with cargo transportation services planned to begin in 2019. Like the current CRS contracts, CRS-2 contracts are milestone-based, fixed-price indefinite delivery/indefinite quantity (IDIQ) contracts.

NASA has purchased crew launches from Roscosmos through 2018, and crew rescue and return through mid-2019. In addition, NASA purchased, through Boeing, crew transportation, rescue, and related services for one USOS crew member on Soyuz in FY 2017 and one in FY 2018. The contract with Boeing also provides Soyuz crew transportation services for three USOS crew members in 2019 to ensure a stable crew plan until domestic commercial crew services are available.

In September 2014, NASA's CCP awarded CCtCap contracts to Boeing and SpaceX for commercial crew transportation. Those awards include at least two service missions per provider, with a maximum of up to six service missions per provider. CCP is funding milestones on the initial service missions, called Post Certification Missions. The Crew and Cargo program will fund the subsequent service missions. These crewed vehicles will provide a minimum of 220 pounds of cargo as specified by the ISS program.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Crew transportation	Roscosmos	Moscow, Russia
Crew transportation	Boeing	Houston, TX
Crew transportation	SpaceX	Hawthorne, CA

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Element	Vendor	Location (of work performance)
Cargo transportation	Orbital ATK	Dulles, VA
Cargo transportation	Sierra Nevada	Louisville, CO
Cargo transportation	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

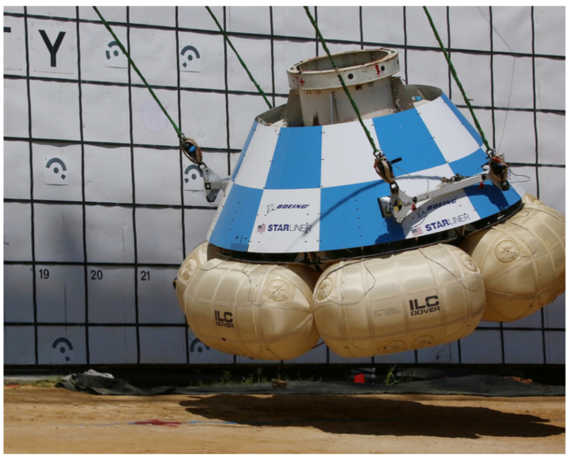
Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Advisory Council	Dec 2017	Provides independent guidance for the NASA Administrator	No new formal recommendations or findings for the ISS	2018
Other	NASA Aerospace Safety Advisory Panel	Oct 2017	Provides independent assessments of safety to the NASA Administrator	No new formal recommendations or findings for the ISS	2018

COMMERCIAL CREW PROGRAM

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	1184.8	--	173.1	35.8	36.3	36.3	36.3

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.



Top Photo: The Boeing CST-100 Starliner spacecraft goes through a series of land landing qualification tests to simulate what the actual spacecraft and crew members may experience while returning to Earth from space at NASA's Langley Research Center in Virginia (July 2017).

Bottom Photo: Personnel from NASA, SpaceX, and the U.S. Air Force practice astronaut recovery operations for the SpaceX Crew Dragon spacecraft at NASA's Kennedy Space Center in Florida (June 2017).

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

With technical guidance and oversight from NASA, the U.S. private sector is working to develop and operate safe, reliable, and affordable crew transportation to space, including to the International Space Station (ISS). Partnering with the commercial space industry for access to ISS and other low Earth orbit destinations bolsters American leadership, reduces our current reliance on foreign providers for this service, and helps stimulate the American aerospace industry. By supporting the development of human spaceflight capabilities, NASA is also laying the foundation for a more affordable and sustainable future for human spaceflight.

Through the Commercial Crew Program (CCP), NASA provides technical and financial support to industry partners during development of their crew transportation systems using milestone-based contracts, and will certify them to carry NASA astronauts to and from the ISS. Under this acquisition model, NASA defines requirements upfront and pays the partner only once contract milestones are successfully completed. This approach shifts financial risk from taxpayers to the private sector, incentivizing increased cost-control, and decreasing the costs of developing the systems.

The first phase of the development effort was a series of competitively awarded Space Act Agreements (SAAs), followed by Certification Products Contracts (CPCs). The CPC effort allowed the partners to gain insight into NASA human spaceflight requirements and gave NASA early insight into partner designs and approaches.

CCP entered the final certification phase with the award of two Commercial Crew transportation Capability (CCtCap) contracts. CCtCap requires both partners to complete design, development, test, evaluation, and certification of an integrated Crew Transportation System. The completed transportation systems will support four NASA or NASA-sponsored crew on each flight, and provide emergency crew return, transport/return of pressurized ISS cargo, and crew safe haven while docked to the ISS.

There are numerous benefits associated with the CCtCap acquisition strategy, such as controlling costs in the long term, and maximizing crew safety, as reinforced in statements by the Government Accountability Office, Aerospace Safety Advisory Panel (ASAP), and NASA Office of Inspector General. The CCtCap contracts incorporate higher level requirements than past development efforts, enabling the partners to be innovative and creative in their designs. Additionally, having more than one commercial partner creates competition providing a strong incentive to perform and does not leave the Government dependent on a sole partner, thereby generally producing lower prices and mitigating the risk of failure of an individual partner. Additionally, under this model, NASA ensures that companies retain commercial rights to intellectual property, which will allow these crew transportation systems to serve a much larger market than just NASA.

The CCtCap awards represent a significant milestone in U.S. human spaceflight, with the goal of ending our sole reliance on foreign crew transportation to the ISS, and certification of safe, cost-effective U.S. commercial crew transportation systems. In addition, this approach helps stimulate growth of new space transportation industry capabilities available to all potential customers, strengthening America’s space industrial base and providing a catalyst for future business ventures that can capitalize on affordable, globally competitive, U.S. space access. Returning these launches to American soil has significant economic benefits, with more than 1,000 suppliers working across nearly every state on commercial crew spacecraft systems.

NASA measures partner progress against fixed-price milestones, based on performance of agreed upon entrance and success criteria. Although the content varies by partner, milestones are designed to demonstrate progress toward completing crew transportation system development, such as risk reduction testing, design reviews, hardware development, and flight tests. The Government pays for milestones only after completion. Also, the partners will own and operate their completed systems. As mentioned in the Crew and Cargo program section, CCP manages the CCtCap contracts. In addition to funding the development and risk mitigation work, CCP also funds each partner's initial Post Certification Missions (PCMs). Subsequent PCMs are funded by the Crew and Cargo program.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

COMMERCIAL CREW PROGRAM

ACHIEVEMENTS IN FY 2017

CCP started the year by securing an additional four crew rotation missions from Boeing and SpaceX. The missions will carry astronauts to and from the ISS through 2024. The four additional missions fall under the CCtCap contracts and bring the total number of crew rotation missions awarded to each partner to six. The missions will fly following NASA certification.

CCtCap development activities made significant progress with each company continuing to develop and test their unique space transportation systems. NASA's four astronauts training to fly the test flights on Boeing's Starliner and SpaceX's Crew Dragon spent time evaluating both partners' progress during 2017. The astronauts are learning about the systems, being fitted for spacesuits, and readying for flight tests to and from the ISS. Designed to meet NASA's safety and functionality requirements, both Boeing and SpaceX unveiled the first look at their new spacesuit designs.

Three Boeing Starliners are in production inside the Commercial Crew and Cargo Processing Facility at NASA's Kennedy Space Center (KSC) in Florida. This year, the Starliner was powered on for the first time, and test versions of the spacecraft have been shipped across the United States to be put through the extremes necessary to understand how the Starliner will perform in the space environment. Other tests are aimed at simulating the actual pressure that the Starliner will encounter during ascent, orbit and reentry to Earth's atmosphere. At the Landing and Impact Research Facility at NASA's Langley Research Center in Virginia, a Starliner mock-up endured a series of land landing qualification tests designed to simulate a crew return to Earth in the Western United States. The capsule is designed for landing on land, making it reusable up to ten times with a six-month turnaround time between launches. Boeing is developing the Starliner to fly on the United Launch Alliance (ULA) Atlas V rocket from Space Launch Complex 41 on Cape Canaveral Air Force Station in Florida. At the ULA facility in Decatur, Alabama, the company made progress on manufacturing the Atlas V that will launch Starliner for its uncrewed flight test in 2018.

SpaceX is manufacturing the Crew Dragon spacecraft inside the company's headquarters and manufacturing facility in Hawthorne, California. In total, SpaceX has six Crew Dragon modules in various stages of production and testing, including a qualification module, a life support system testing module, two spacecraft for flight tests and the first two for fully operational missions. SpaceX built a test version of its Crew Dragon solely for evaluation of the life support system that will provide tight control of parameters that are important to human safety such as temperature, carbon dioxide levels, oxygen levels and cabin pressure. The environmental control and life support system (ECLSS) was extensively tested and evaluated at the company's headquarters. In February, SpaceX hosted its inaugural flight from historic Launch Complex 39A at KSC. The company successfully launched 12 missions from 39A in 2017 gaining experience utilizing the pad for future commercial crew missions.

Both CCtCap partners have experienced some delays that are typical in a complex spaceflight development effort. This is a large, complex development effort whereby the partners are expected to conform to a set of requirements in a fixed price contract. Also, there is a large amount of work required of NASA to verify and validate all requirements have been met. These challenges have resulted in some schedule adjustments over the past year.

CCP continued work with Blue Origin and Sierra Nevada to develop and refine their respective spacecraft and launch systems. Under the CCDev2 and Commercial Crew Integrated Capability Space Act Agreement (CCiCap) agreements, NASA provides expertise and insight into their spaceflight designs.

COMMERCIAL CREW PROGRAM

WORK IN PROGRESS IN FY 2018

Boeing and SpaceX, will complete several significant CCtCap milestones necessary to develop and test their crew transportation systems. To meet NASA's requirements, the commercial partners must demonstrate that their systems are ready to begin regular flights to ISS. Two of those demonstrations are uncrewed flight tests which will occur in FY 2018, known as Orbital Flight Test for Boeing, and Demonstration Mission 1 for SpaceX. After the uncrewed flight tests, each company will carry out a flight test with crew in FY 2019 prior to being certified by NASA for crew rotation missions.

By the end of the fiscal year, NASA expects Boeing to have completed 36 of 39 milestones. This includes a major review milestone, the ISS Design Certification Review. Boeing's spacesuit, designed to meet NASA's safety and functionality requirements, will continue to undergo integrated system verification tests, including environmental control and life support system testing. Boeing will continue with the production and outfitting of three spacecraft crew modules and multiple service modules inside the Commercial Crew and Cargo Processing Facility at Kennedy Space Center in Florida. In addition, Boeing and United Launch Alliance will make final preparations to the launch pad to ready the Atlas V complex for human spaceflight.

By the end of the fiscal year, NASA expects SpaceX to have completed 21 out of 25 milestones. Like Boeing, this includes a Design Certification Review. SpaceX will continue forward work on their six spacecraft crew modules the company currently has in various stages of production and testing. SpaceX will also continue ongoing qualification and validation testing on its advanced spacesuits in FY 2018, including suit-fit and pressure tests. The company is in the process of manufacturing custom suits for each of the four astronauts, which will ensure a proper fit and comfortable ride to and from the ISS in their designed spacecraft in 2018. SpaceX will also continue upgrading LC-39A to support upcoming commercial crew missions, and the company's Crew Access Arm will be installed on the launch pad to provide a bridge between the crew access tower and SpaceX's Crew Dragon spacecraft for astronauts flying to the space station on the company's Falcon 9 rocket.

Sierra Nevada's Dream Chaser spacecraft completed a series of tests at NASA's Armstrong Flight Research Center located on Edwards Air Force Base in California. The testing culminated with a free flight test where the uncrewed spacecraft was lifted about 12,400 feet into the air by a helicopter and then released for a successful approach and landing, leading to the completion of a major milestone in early FY 2018 under CCiCap. The tests helped Sierra Nevada validate the aerodynamic properties, flight software and control system performance of the Dream Chaser under CCiCap.

SpaceX also continued progress toward completing their final CCiCap milestones. SpaceX split their In-flight Abort Test milestone and completed the first portion, the In-flight Abort Test Checkpoint, in early FY 2018. They will complete the final part of that milestone in FY 2019.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

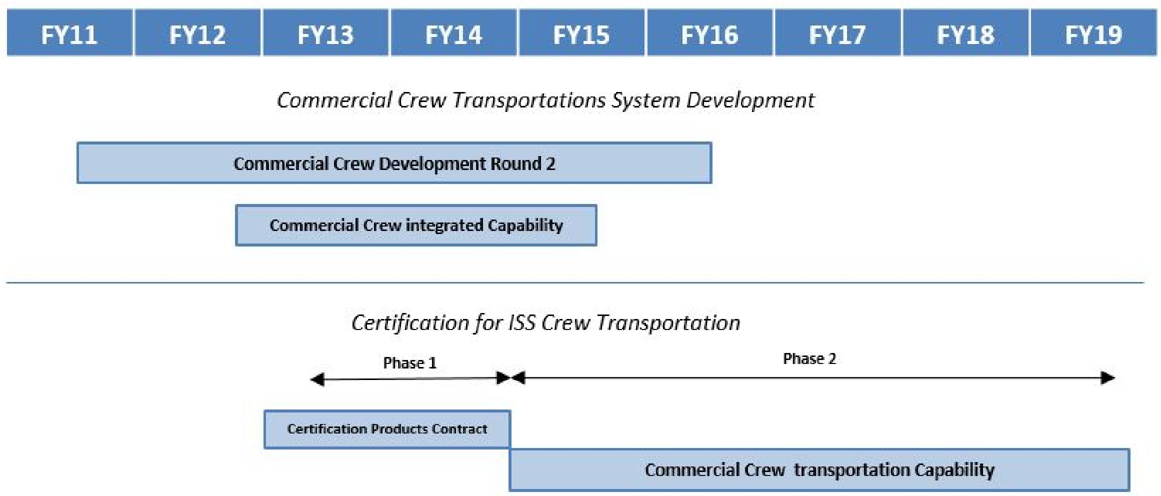
Under CCtCap, both industry partners are planning to complete all development milestones in FY 2019. This includes milestones supporting their crewed demonstration missions and Certification Reviews, the final development milestone on both contracts. Boeing is on contract to complete certification by January 2019. SpaceX is on contract to complete certification by February 2019.

COMMERCIAL CREW PROGRAM

These missions will represent major milestones in the return of human spaceflight from the United States. They will serve as precursors to fully operational crew rotation missions under CCP. After NASA certification, both partner space transportation systems will begin regularly flying astronauts to and from the ISS on NASA missions later in FY 2019.

Program Schedule

Progression of Commercial Crew development efforts.



Program Management & Commitments

The HEOMD team at NASA Headquarters performs strategic management and oversight of Commercial Spaceflight, while KSC is responsible for CCP management, in collaboration with the Johnson Space Center (JSC). CCP partners with industry leaders, are utilizing a combination of SAA and Federal Acquisition Regulation (FAR)-based fixed-price contracts to stimulate efforts to develop and demonstrate crew transportation capabilities.

Program Element	Provider
Commercial Crew Program	Provider: Blue Origin, Boeing, Sierra Nevada, SpaceX Lead Center: KSC Performing Center(s): All Cost Share Partner(s): Industry Partners (shown above)

Acquisition Strategy

CCP facilitates development of a U.S. commercial crew space transportation capability with the goal of achieving safe, reliable, and cost effective access to and from space and the ISS. Under the partnership approach, NASA engineers have insight into a company's development process and evaluate the systems for overall safety, reliability, and performance. The Agency's technical expertise and resources are also accessible to a company. Because companies are only paid a fixed amount, they are incentivized to reduce costs, and apply their most efficient and effective manufacturing and business operating techniques throughout the process. Additionally, the companies own and operate their own spacecraft.

In the early lifecycle stages, CCDev activities focused on stimulating industry efforts that successfully matured subsystems and elements of commercial crew spaceflight concepts, enabling technologies and capabilities. This was followed by CCDev2, which addressed new concepts to mature design and development of primary elements, such as launch vehicle or spacecraft. Subsequently, NASA continued this effort with CCiCap SAA to continue partner progress in their integrated design and development efforts. For these initial efforts, NASA utilized SAAs, which provided maximum flexibility to the provider and maximum affordability to the Government. Concurrently with CCiCap agreements, NASA awarded Certification Products Contracts (CPCs) to industry to begin the process of NASA certifying their crew transportation systems. The scope of the CPCs included the submittal and technical disposition of specific, early development certification products. The current and final stage of the acquisition lifecycle began with the award of two FAR-based fixed-price CCtCap contracts in September 2014 for the development, test, evaluation, and final NASA certification of a Crew Transportation System. CCtCap contracts include demonstration of crewed ISS missions and subsequent service missions, assuming sufficient budget and technical progress, and a Special Studies Services section, for special studies, tests, or analyses, as needed by NASA, to reduce Program risk. NASA's FAR based fixed-price contracts during this phase allows for compliance with NASA's existing mission and safety requirements for transporting crew to and from ISS. The Agency's technical expertise and resources are also accessible to each partner. Because partners are only paid a fixed amount, they are incentivized to reduce costs, and apply their most efficient and effective manufacturing and business operating techniques throughout the process.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
CCDev2 (follow-on)	Blue Origin	Kent, WA
CCtCap	Boeing	Houston, TX
CCiCap	Sierra Nevada	Louisville, CO
CCiCap/CCtCap	SpaceX	Hawthorne, CA

COMMERCIAL CREW PROGRAM

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Advisory Council	Dec 2017	Provide independent guidance for the NASA Administrator	TBD	TBD
Other	ASAP	Oct 2017	Provide independent assessments of safety to the NASA Administrator	No new formal recommendations or findings	2018
Other	SRB	Nov 2017	Assess funding and schedule reserve requirements, cost effectiveness during development and impacts to future sustaining operations, and efforts required for successful program implementation	While the SRB identified some risks, issues, and concerns, it found that the program has made good progress the last year proceeding towards the production and test phase of the program.	Fall 2018

Historical Performance

Through FY 2017 (funded milestones only).

As of September 30, 2017

Commercial Orbital Transportation System (COTS) Partner	No. of Milestones	Total Potential Value (in $M)	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
SpaceX	40	396.0	40	396.0	100%	100%	Completed
Orbital	29	288.0	29	288.0	100%	100%	Completed
Rocketplane-Kistler	15	206.8	3	32.1	20%	16%	Terminated

CCDev1 Partner	No. of Milestones	Total Potential Value (in $M)	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
Sierra Nevada	4	20.0	4	20.0	100%	100%	Completed
Boeing	36	18.0	36	18.0	100%	100%	Completed
Blue Origin	7	3.7	7	3.7	100%	100%	Completed
Paragon Space Development Corporation	5	1.4	5	1.4	100%	100%	Completed
United Launch Alliance	4	6.7	4	6.7	100%	100%	Completed

CCDev2 Partner	No. of Milestones	Total Potential Value (in $M)	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
Sierra Nevada	13	105.6	13	105.6	100%	100%	Completed
Boeing	15	112.9	15	112.9	100%	100%	Completed
SpaceX	10	75.0	10	75.0	100%	100%	Completed
Blue Origin	10	22.0	10	22.0	100%	100%	Completed

CCiCap Partner	No. of Milestones	Total Potential Value (in $M)	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
Sierra Nevada	11	227.5	10	219.5	91%	96%	Active
Boeing	20	480.0	20	480.0	100%	100%	Completed
SpaceX	15	460.0	14	430.0	93%	93%	Active

CCtCap Partner	No. of Milestones	Total Potential Value* (in $M)	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
Boeing	36	2,023.9	22	1,367.9	61%	68%	Active
SpaceX	19	1,206.1	10	655.0	53%	54%	Active

* Total Potential Value cited is limited to the design, development, test, and evaluation portion of the contracts. Excludes post certification mission and special studies milestones.

SPACE COMMUNICATIONS AND NAVIGATION

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Space Communications Networks	546.9	--	**523.4**	454.8	504.3	549.8	567.4
Space Communications Support	83.2	--	**110.8**	114.1	111.3	103.1	103.2
Total Budget	**630.1**	**--**	**634.1**	**568.8**	**615.6**	**652.9**	**670.6**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

The Tracking and Data Relay Satellite (TDRS-M) successfully launched August 18, 2017. The geosynchronous TDRS fleet operates 24 hours a day, 7 days a week providing communication and tracking services to missions in low Earth orbit.

The Space Communications and Navigation (SCaN) Program is embarking on the development of a new space communication and navigation architecture to meet the expanding requirements of NASA science and exploration missions. With the introduction of commercial services and capabilities and new technology such as optical communication, NASA's space communication and navigation capabilities will provide mission-critical communications and navigation required by all NASA spaceflight missions. These missions range from high altitude balloons, to satellites in low Earth orbit, to the most distant manmade object – which is currently over 13 billion miles from Earth — Voyager 1. SCaN retrieves science, spacecraft, and crew health data for all of these missions, uploads commands and sends data to individual control centers. Navigation services determine the precise location of a satellite in order to enable course changes, interpret science data, and position the spacecraft for communication opportunities.

Without SCaN services to move data and commands between spacecraft and Earth, customer missions and space hardware worth tens of billions of dollars would be little more than orbital debris. SCaN provides secure, reliable, and adaptable communication services to NASA internal customers, as well as external customers who rely on these space communications capabilities on a daily basis. External customers include foreign governments, international partners, commercial entities such as launch service providers, and non-NASA U.S. missions to which SCaN provides services to on a reimbursable basis.

SCaN's three communications networks, the Space Network (SN), Near Earth Network (NEN), and Deep Space Network (DSN), provide these critical services to customer missions. SN communicates with missions in low Earth orbit, such as the Hubble Space Telescope (Hubble), and provides constant communication with ISS, as well as its commercial and international partner servicing vehicles. In the future, it will also support Commercial Crew providers and launches of the Space Launch System (SLS) and Orion spacecraft. The NEN communicates with suborbital missions and missions in low Earth orbit, highly elliptical Earth orbit, and some lunar orbits. NEN supports a number of science and weather missions. DSN communicates with the most distant missions, such as interplanetary probes.

The three networks require maintenance, replenishment, modernization, and capacity expansion to ensure continued operation. The SCaN program also includes support to ground communications links that move data between ground stations, NASA centers, data centers, and mission operation centers. In addition, NASA uses the SCaN provided Goldstone Solar System Radar to track and characterize near Earth objects that pass within nine million miles of Earth, and helps determine their orbits for use by the Science Mission Directorate's (SMD) Planetary Science Division in assessing the probability of a conjunction. SCaN is working to upgrade this capability to a distance of 42 million miles, which increases the time to develop viable solutions to avoid orbital collision.

SCaN networks make good use of public-private partnerships to support their various customers. The NEN currently makes use of a mix of Government-owned and commercial ground antennas in order to maximize the network's geographic coverage, minimize the impact of weather-related communications disruptions, and effectively manage financial resources. In addition, SCaN is currently studying options for the long-term sustainment of the SN. A broad range of technical capabilities for the future SN architecture are under consideration. Within the Space Communications Networks project, the Budget includes $25 million to support the development and initial piloting of a strategy to transition the Space Network to a mix of commercial services, where available, and public-private partnerships (where new technologies are needed).

Space Communications Support provides efficient planning and integration of current and future network capabilities to meet customer mission needs while reducing costs. These include systems engineering, architecture planning, communications data standards, technology development, testbeds for future capabilities, radio frequency spectrum management, and navigation policy.

Operating in space requires significant international coordination. SCaN participates in several international organizations that coordinate compatibility and interoperability in space communications and navigation. SCaN's standards development and management activity maintains a portfolio of international interoperability standards that enable joint space missions with other nations. SCaN also promotes new technologies and provides technical leaders and domain experts who ensure appropriate space communication standards are available to NASA missions. The research and technology avenues within SCaN aim to predict the needs of future communications missions in a manner that will yield initiatives with performance advancements and a reduction in costs.

Amid soaring demand for wireless broadband, such as 3G and 4G mobile services, radio frequency spectrum management has become increasingly critical to the world's spacefaring nations. SCaN coordinates nationally and internationally to protect radio frequencies critical to NASA space missions.

For more information, go to http://www.nasa.gov/scan.

EXPLANATION OF MAJOR CHANGES IN FY 2019

In FY 2017, SCaN replanned the Space Network Ground Sustainment (SGSS) project following the replacement of the contractor's and Government's project managers. The replan concluded that the funding required in FY 2018 and FY 2019 for SGSS to reach an initial Operations Readiness Review (ORR) had increased by $117.2 million above previous estimates. At first ORR, the software pool is installed and tested out on one antenna at the White Sands Complex. The remaining antennas at White Sands and other locations would need to be refurbished and tested one at a time after that first ORR, and the software would undergo troubleshooting and debugging as required. Additional funding would be required for the work to be completed after the initial ORR. As a result, NASA is initiating an independent review of the project which will be completed in mid-2018. Given the budgetary challenges encountered by the project, the FY 2019 Budget does not provide funding for the continuation of SGSS. A final decision on SGSS continuation will be deferred until the conclusion of the independent review. If the results of this review point towards an affordable path forward for SGSS, NASA will look for opportunities to continue SGSS.

SPACE COMMUNICATIONS NETWORKS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Next Generation Capability	0.0	--	**100.0**	39.6	52.7	93.0	110.4
Total Budget	**546.9**	**--**	**523.4**	**454.8**	**504.3**	**549.8**	**567.4**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

The Tracking and Data Relay Satellite (TDRS-M) spacecraft was launched in August 2017, heralding the end of the launch effort and the mission's beginning. Following several months of calibration and testing, TDRS-M will be renamed TDRS-13, and it will be eligible to begin supporting NASA's Space Network.

The Space Communication and Navigation (SCaN) networks are comprised of the Space Network (SN), Near Earth Network (NEN), and Deep Space Network (DSN). Together they provide a 24/7 global, near-Earth and deep-space communications system, plus tracking and navigation services to over 100 NASA, other U.S. Government, international civil space agency and commercial missions.

SCaN supports new spacecraft that are increasingly powerful, complex and capable of acquiring ever increasing amounts of mission data, as well as missions launched over 30 years ago, such as Voyager 1 and Voyager 2, that are still returning valuable science data. Each network supports a different set of customer requirements for spacecraft orbit, signal strength and real-time coverage. In order to continue providing proficiency at or above 95 percent for customer missions, each network requires regular maintenance, modernization and capacity expansion.

NASA's space communications networks provide ongoing services to Agency and customer missions, averaging about 600 tracking passes per day. Without these capabilities, customer missions like Geostationary Operational Environmental Satellites (GOES)-R, Joint Polar Satellite System (JPSS)-1, Cyclone Global Navigation Satellite System (CYGNSS) and James Webb Space Telescope (Webb) would not be able to deliver key science data.

The SN provides continuous global coverage to NASA missions in low Earth orbit (LEO), and to launch vehicles during their launch and ascent phase. It is the primary U.S. communications link to the ISS, as well as for ground and balloon research in remote locations, such as the South Pole. The SN consists of NASA's Tracking and Data Relay Satellite (TDRS) system of communications satellites in geosynchronous orbit; a set of space-to-ground link terminals at NASA's White Sands Complex in New

SPACE COMMUNICATIONS NETWORKS

Mexico; and remote space-to-ground terminals in Guam, and at Blossom Point, Maryland. The ground systems operate the TDRS fleet and route customer mission data between TDRS and ground terminals. Maintaining and modernizing this critical network is one of the Agency's top priorities. To accomplish this, NASA is requesting $25 million in FY 2019, with additional funding in subsequent years, to support the development and initial piloting of a strategy to transition the Space Network to a mix of commercial services, where available, and public-private partnerships (where new technologies are needed). Initial transition efforts will focus on working with the commercial market to identify requirements that are mutually beneficial to NASA and industry and developing an acquisition model for incorporating commercial communications services or hosted payloads into the SN. Once this acquisition model has been proven, NASA will incorporate it into next-generation technologies such as laser communications into the network while continuing to support the requirements of legacy users.

The NEN provides space communications to missions in low Earth, geosynchronous, lunar and highly elliptical Earth orbits, as well as from certain suborbital launch locations. Comprised of NASA-owned and commercial satellite communication stations, the NEN is located throughout the world. The NASA owned network's ground stations are located at White Sands in New Mexico; U.S. McMurdo Antarctic Station; Wallops Flight Facility (WFF), Chincoteague, Virginia; and University of Alaska, Fairbanks, Alaska. The network also purchases services from commercial providers in Hawaii, Norway, Sweden, Singapore, South Africa, Australia and Chile. The NEN provides telemetry, tracking and command services to an extensive and diverse customer base, including the high-rate Earth Observing System, and several Small Explorer missions. The NEN is currently augmenting its ground station network to provide communications services for future spacecraft including Orion and the Space Launch System (SLS).

The DSN, which has been in operation for over 50 years, provides communication and tracking services to about 35 NASA and non-NASA missions beyond geosynchronous orbit (over 26,000 miles above the Earth's surface). Its three deep space communication complexes, all of which are owned by NASA, are located in Goldstone, California; Canberra, Australia; and Madrid, Spain. The sites are separated by approximately 120 degrees of longitude to ensure that any spacecraft in deep space can communicate with at least one station at all times as the Earth rotates.

The SCaN Program actively seeks to implement operational efficiencies to help fund modernization and upgrade activities. One example of this is Follow-the-Sun Operations. Since the three DSN ground stations are spaced roughly equally apart on the globe, each station will be responsible for operating the entire DSN network during their day shift, handing off control to the next site as their day ends. While each station will still need a small emergency staff during their off-shift hours, these remote operations will significantly reduce operating costs at each station.

The ongoing DSN Aperture Enhancement Project modernizes and upgrades the DSN's ground stations to enhance capacity, improve flexibility to support customer missions, and reduce operations and maintenance costs. The project will augment the 70 meter antennas in California, Spain and Australia with arrays of four 34 meter Beam Waveguide (BWG) antennas by 2025. Antenna arraying combines the signals received by multiple antennas to function as a single large antenna – in this instance as a 70 meter antenna or less as required. The BWG antennas are less complicated, more flexible, and more cost-effective to maintain than conventional antennas. In addition, they provide the same or better performance as the 70 meter antennas. When not needed by a mission for arraying all four antennas, the 34 meter antennas may support multiple spacecraft as needed individually or by arraying two or three of the 34 meter antennas. Construction efforts, such as new 34 meter antennas, use Construction of Facilities funds appropriated in NASA's Construction and Environmental Compliance and Restoration account.

The NASA Communications Services Office (CSO) is a centralized commercial service provides point-to-point communication services between the three space communications network ground stations, NASA centers, customer mission operations and data centers. While NASA's Office of the Chief Information Officer manages the CSO service, it is funded by the SCaN program.

For more information, go to http://www.nasa.gov/scan.

EXPLANATION OF MAJOR CHANGES IN FY 2019

In FY 2017, SCaN replanned the Space Network Ground Sustainment (SGSS) project following the replacement of the contractor's and Government's project managers. The replan concluded that the funding required in FY 2018 and FY 2019 for SGSS to reach an initial Operations Readiness Review (ORR) had increased by $117.2 million above previous estimates. At first ORR, the software pool is installed and tested out on one antenna at the White Sands Complex. The remaining antennas at White Sands and other locations would need to be refurbished and tested one at a time after that first ORR, and the software would undergo troubleshooting and debugging as required. Additional funding would be required for the work to be completed after the initial ORR. As a result, NASA is initiating an independent review of the project which will be completed in mid-2018. Given the budgetary challenges encountered by the project, the FY 2019 Budget does not provide funding for the continuation of SGSS. A final decision on SGSS continuation will be deferred until the conclusion of the independent review. If the results of this review point towards an affordable path forward for SGSS, NASA will look for opportunities to continue SGSS.

ACHIEVEMENTS IN FY 2017

During the fiscal year, the space communications networks supported over 100 missions, with over 325,000 hours of tracking and more than 245,000 passes. SCaN networks provided launch to splash-down communication support for ten human spaceflight missions, nine expendable launch vehicle (ELV) missions, and three new robotic missions. SCaN continued to replenish networks to upgrade and replace obsolescent equipment to ensure continued tracking and data transmission for its customers in support of current and future missions.

TDRS-M launched on August 18, 2017. After on-orbit acceptance of TDRS-M in FY 2018, the SN will have adequate capacity for its expected mission set until the second-generation TDRS begin retiring in the mid-2020s. The SCaN program completed its initial study of options for the long-term sustainment of the SN, and awarded and completed follow-on study contracts. A broad range of technical capabilities for the future SN architecture are under consideration.

The SGSS project is an upgrade to the ground segment of the SN. SGSS completed software development delivery and began integration and test activities.

NEN completed replacement of AS2 antenna at the Alaska Satellite Facility, which had become obsolete and inoperable. This replacement provides backup to the AS1 and AS3 antennas while they are being

SPACE COMMUNICATIONS NETWORKS

upgraded to Ka-band and also provides additional network capacity. NEN completed development of Launch Communication Stations at KSC, with testing and verification ongoing to make that site operational to support EM-1, and continued work at the Bermuda site.

The DSN Follow-the-Sun Operations upgrade will be completed in two phases. Phase 1 is Follow-the-Sun remote operations and Phase 2 enables one operator to control three antennas simultaneously. In FY 2017, DSN completed development of Phase 1 and began its operational transition into remote operations. Development of Phase 2 work continued with plans for completion in FY 2020.

The DSN Aperture Enhancement Project continues efforts to upgrade and replace existing antennas at its complexes. Construction continued on two new antennas at the Madrid Deep Space Communications Complex (MDSCC) in Spain, Deployable Space System (DSS)-56 and DSS-53. These new antennas will augment the 70 meter antenna located at this site. The foundation and walls are complete for both antennas, as well as the roof for DSS-56.

WORK IN PROGRESS IN FY 2018

The three space communications networks will continue to provide a level of service similar to that provided in prior years. This includes over 245,000 tracking passes, totaling more than 325,000 hours, while maintaining an extremely high level of proficiency (approximately 99.95 percent or higher), well above the 95 percent required by the SCaN Program Commitment Agreement. SCaN networks are planning to support 13 human spaceflight, 13 ELV, and 10 robotic mission launches.

The SN will complete its replacement of the uninterruptable power supply module at White Sands, New Mexico. In addition, other White Sands ground equipment upgrades will provide up to 600 Mbps Ku-band data service. This additional capability is needed to meet ISS requirements and will enable ISS to increase its science capabilities by supporting high definition cameras and the transfer of large amounts of science data quickly and in real time instead of storing the data onboard and waiting for a sufficiently large time to complete a downlink or for a data recorder to return to Earth.

The SGSS prime contractor will continue integration and test activities in anticipation of a systems acceptance test in late FY 2018. An independent review will be conducted on the SGSS project due to contract performance issues and uncertain budget and schedule requirements in the coming years.

The NEN began Ka-Band upgrades at the Alaska Satellite Facility, which are scheduled for completion in FY 2020. It will complete depot level maintenance of an 11 meter antenna at the Wallops Ground Station, on Wallops Island, Virginia. These activities include steps to proactively inspect and replace cables and mechanical systems that are reaching their failure threshold, and are not otherwise addressed by preventative maintenance. The NEN will also complete development of the Launch Communication Station at the Bermuda site, the final milestone for that project.

DSN Follow-the-Sun Operations will complete their Phase 1 operations transition and continue development of Phase 2, scheduled for completion in FY 2020. The DSN Aperture Enhancement Project will also continue construction of DSS-56 and DSS-53 antennas in Spain, completing both pedestals.

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KEY ACHIEVEMENTS PLANNED FOR FY 2019

The SCaN Network will continue to provide communications, tracking and navigation services to over 100 NASA, U.S. Government, civil space agency, and commercial missions at 95 percent or higher proficiency rate. This includes providing launch support on all new human spaceflight, ELV, and robotic missions. All three networks will continue to identify and implement methodologies and processes, as well as upgrade equipment, to achieve improvements over historical operational efficiencies and goals.

SCaN is developing a plan to provide next generation Earth relay operational communications capability by 2025. Past networks have been expensive to operate and maintain because they were designed to only serve government customers, which has limited their ability to leverage commercial partnerships. The next generation project will engage with commercial industry through mechanisms such as services contracts, hosted payloads, and other public-private-partnerships to allow multiple commercial entities to partner with the Government in order to significantly reduce and eventually eliminate reliance on NASA or NASA contractor run ground systems. This will bolster American industry and significantly reduce the cost of NASA's communication network. In addition, the SCaN program will also complete its study of options for the long-term sustainment of the SN, and award follow-on study contracts.

NEN will begin depot level maintenance of an 18 meter antenna at the White Sands facility. These activities include steps to proactively inspect and replace cables and mechanical systems that are reaching their failure threshold, and are not otherwise addressed by preventative maintenance. NEN will also continue Ka-Band upgrades at the Alaska Satellite Facility scheduled for completion in FY 2020.

In Madrid, Spain, the DSN Aperture Enhancement Project will complete antenna fabrication for DSS-56 and will begin the related installation, integration and test activities to support operations in FY 2020. Installation, integration and test activities will also begin on DSS-53, scheduled for completion in FY 2021. These new antennas will transmit and receive across a wide range of radio frequencies for deep space communication with interplanetary robotic spacecraft to provide required capabilities for the expected growth of deep space missions launching over the next decade. Construction for DSS-33 is scheduled to begin in FY 2019 and DSS-23 in FY 2021.

DSN sustaining items include antenna pointing and control system upgrades in Australia starting in second quarter of FY 2018, exciter obsolescence work in California with phase 1 completion scheduled for end of FY 2018, and network-wide Ka-band uplink upgrades scheduled for completion by FY 2020.

Project Schedule

The table below includes significant SCaN network milestones in FY 2018 and FY 2019.

Date	Significant Event
FY 2018- Q1	DSN successful implementation of Follow-the-Sun efficiency operations at all three complexes
FY 2018 - Q2	SN on-orbit acceptance of TDRS-M
FY 2018 - Q2	DSN complete Phase 1 Follow-the-Sun Transition

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Date	Significant Event
FY 2018 - Q3	NEN Launch Communication Stations at Florida and Bermuda complete Operational Readiness Reviews
FY 2018 - Q3	Independent Review of SGSS Project
FY 2018 - Q3/4	Decision on continuation of the SGSS project
FY 2018 - Q4	SN uninterruptable power supply module replacement at White Sands complete
FY 2018 - Q4	SGSS Systems Acceptance Test Complete
FY 2019 - Q3	NEN complete White Sands 18 meter depot level maintenance
FY 2019 - Q3	DSN start implementation of Three Links per Operator efficiency task
FY 2019 - Q3	SN complete STPSat-6 Antenna and Ground Equipment ORR

Project Management & Commitments

Element	Description	Provider Details	Change from Formulation Agreement
Space Network	Communication and navigation services to customer missions in low Earth orbit and launch vehicles	Provider: Space Network Project Office Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): Non-NASA customers	N/A
NEN	Communication and navigation services to customer missions in low Earth, highly elliptical, and lunar orbits	Provider: NEN Project Office Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): Non-NASA customers	N/A
DSN	Communication and navigation services to customer missions in deep space	Provider: DSN Project Office Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): Non-NASA customers	N/A
NASA CSO	Centralized commercial service that provides point-to-point communication services between ground sites	Provider: CSO, through NASA Chief Information Officer Lead Center: NASA HQ Performing Center(s): MSFC, GSFC Cost Share Partner(s): N/A	N/A

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Element	Description	Provider Details	Change from Formulation Agreement
TDRS Replenishment	Purchase third-generation TDRS-K, -L, and -M to maintain Space Network communications services to customer missions into the 2020s	Provider: Boeing Space Systems Lead Center: GSFC Performing Center(s): N/A Cost Share Partners: Other U.S. government agencies	Development cost reduced. TDRS-M added to purchase
SGSS	Replace outdated and deteriorating ground systems at Space Network ground terminals	Provider: SGSS Project Office Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): Non-NASA U.S. government partners	N/A

Acquisition Strategy

The major acquisitions for the networks are in place. NASA uses reimbursable, international and barter agreements, as well as competitive procurements. NASA's JPL provides the management of the DSN. The next generation earth relay is being designed to rely on commercial services and other public private partnerships. This new architecture will encourage the deployment of commercially-operated services or capabilities that can support NASA requirements as well as the much larger set of current and future industry customers.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
DSN	JPL/Cal Tech	Pasadena, CA
Space Network Operations	Peraton	Herndon, VA
NEN Operations	Peraton	Herndon, VA
TDRS Replenishment and modifications to Space Network ground systems to support these spacecraft	Boeing Space Systems	El Segundo, CA
TDRS-M Launch Vehicle	United Launch Alliance, LLC	Centennial, CO
SGSS	General Dynamics Mission Systems	Scottsdale, AZ

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INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
SCaN	Standing Review Board	October 2016	Program Implementation Review with focus on interdependencies, implementation planning, and risk gaps or shortfalls	Success criteria met. Major strengths, observations, concerns and issues were identified	FY 2018

SPACE COMMUNICATIONS SUPPORT

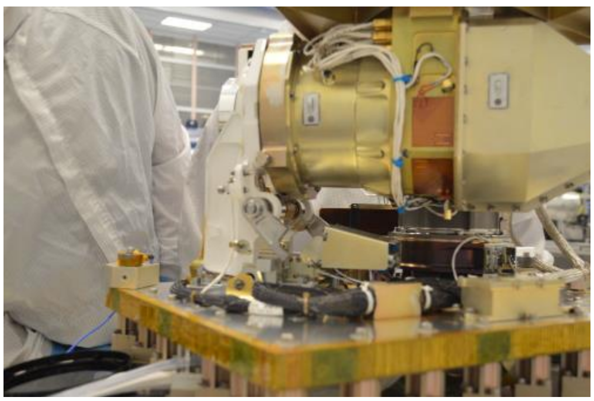
Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	83.2	--	110.8	114.1	111.3	103.1	103.2

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



The complete Laser Communications Relay Demonstration (LCRD) payload is being assembled for test in the clean room at NASA Goddard Space Flight Center. Scheduled to launch in 2019, the Laser Communications Relay Demonstration (LCRD) will simulate communications support, practicing for two years with a test payload on the International Space Station and two dedicated ground stations in California and Hawaii.

The Space Communications Support project supports NASA and the SCaN program through communications and navigation planning, management, and technology development.

Within the Space Communications Support project, SCaN’s architecture planning and systems engineering office defines technical services, capacity, and performance requirements to eliminate duplication across networks, minimize mission-unique requirements, ensure customer missions operate together with NASA networks, and lower development and operations costs. SCaN is conducting studies to identify future space-based relay communication and navigation architectures for Earth, the Moon, and Mars that are infused with technologies under development to support NASA missions in the 2022 and beyond timeframe. These studies include Requests for Information (RFI) to leverage the creativity of industry partners through mechanisms such as public-private partnerships that will be central to NASA's future communications architecture.

Evolving space communication systems will transform future NASA mission capabilities. SCaN’s technology development effort invests in leading-edge communications technologies, and enables, improves, and matures available spacecraft communication and navigation technologies to build capabilities for both ground and space-based use. Technology items are created and tested in lab settings before they are taken into space for further testing. Demonstrable technologies have proven themselves in laboratory tests and have begun experimentation and testing in space. Key demonstrable technologies that SCaN is currently developing are optical communication and software-defined radios.

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Formulation	Development	Operations

Optical communication is a form of long distance communication using lasers as a means of transmitting information and has the potential to dramatically increase efficiency, while being less expensive to operate and inherently more secure than radio communications. This technology has the potential to create an entirely new field of business for U.S. industry. In cooperation with industry partners, SCaN is developing a plan for transitioning optical communication technology from a demonstration capability into an operational service.

NASA's Space Technology Mission Directorate [((STMD), the new ER&T organization)] and SCaN are jointly developing the Laser Communications Relay Demonstration (LCRD). SCaN is funding ground operations and STMD (the new ER&T organization) is funding the payload. LCRD will be NASA's first long-period optical communications project that will demonstrate benefits for both deep space and near Earth missions. To transmit a 30 centimeter resolution map of the entire Martian surface (at one bit/pixel) would take current radiofrequency (RF) systems two years – a laser communications system operating at projected capacity would be able to complete transmission in nine weeks. Construction efforts, such as for LCRD ground stations, use Construction of Facilities funds appropriated in NASA’s Construction and Environmental Compliance and Remediation account.

SCaN and STMD (the new ER&T organization) are also working together on the Deep Space Atomic Clock (DSAC) demonstration which will allow a spacecraft to calculate its own timing and navigation data in real time. With existing technology, a spacecraft can be navigated autonomously to the top of the Martian atmosphere with a 1 to 2 km uncertainty. It is expected that DSAC will enhance deep space navigation and reduce positional uncertainty to 100 meters, improved by a factor of 10 to 20 over today's capabilities, which will save precious fuel and enable more accurate scientific measurements. DSAC also enables on-board navigation for robotic missions or crewed missions.

SCaN is an active member of multiple international organizations (e.g. Interagency Operations Advisory Group) that coordinate space communication and navigation compatibility and interoperability, as well as the development of communications and data systems standards for spaceflight. Space communications data standards enable the world space agencies to provide cross support to each other, reducing mission risk and reducing or eliminating the need to build and deploy their own space and ground assets resulting in significant cost savings to NASA without reducing services and coverage to space missions.

Electromagnetic spectrum is a valuable and limited natural resource that all NASA missions and most operations require for communications, navigation, and data services in the areas of Earth science, space science, human space exploration, and aeronautical research. All forms of wireless communication systems use the electromagnetic spectrum, so the spectrum must be carefully controlled and coordinated. SCaN is responsible for ensuring access to the portions electromagnetic spectrum necessary to support NASA's mission needs. This includes ensuring interference-free operations and sufficient bandwidth is available. SCaN serves as the Agency's Spectrum Manager and provides the NASA representatives to domestic and international spectrum governing bodies. In the U.S., NASA provides representatives to the Interdepartment Radio Advisory Committee at the National Telecommunications and Information Administration (NTIA). Internationally, NASA is a U.S. delegate to a multitude of forums, the most important of which are the World Radiocommunication Conferences, which convene every three to four years and include delegates from more than 150 nations. Among the purposes of these Conferences is to review and revise the International Telecommunication Union's Radio Regulations which govern the use

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

of electromagnetic spectrum, define frequency allocations, and refine the mechanisms by which use of electromagnetic spectrum by satellites is coordinated across the globe.

NASA spacecraft in Earth orbit employ GPS timing signals for precision positioning, navigation, and timing for vehicles in space. This allows NASA to minimize the network communications and tracking burdens while maximizing spacecraft autonomy and operations. SCaN manages NASA's policy on GPS use and plays a major role on the national and international position, navigation, and timing policy, helping to ensure compatibility and interoperability among U.S. Government capabilities and other spacefaring nations, promoting common definitions and specifications, and mitigating threats to the GPS spectrum.

For more information, go to https://www.nasa.gov/scan.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

SCaN baselined NASA's space communications network requirements, architecture, and concept of operations to upgrade the three networks into a more unified infrastructure with interoperable, standardized services to user missions. Efforts continued to insert new technologies and advance next generation near Earth (TDRS system replacement) and deep space (Lunar and Mars networks) architecture options in coordination with NASA's Exploration and Science programs. SCaN released a RFI in late FY 2017 to explore alternative business models for acquisition and operation of its communications networks to reduce cost and use commercial capabilities where possible. Several RFIs were released to industry to validate architecture options and solicit innovative approaches for the Next Generation Architecture. SCaN will evaluate the responses to the RFI in FY 2018.

SCaN's work with STMD and external partners on LCRD development continued, including the completion of major reviews for both Optical Ground Station (OGS)-1 and OGS-2, the new dedicated ground terminals to support SCaN's evolving optical communications infrastructure. OGS-1 completed its System Integration Review to evaluate the readiness of the project to begin its assembly, integration, and test. In addition to completing facility construction, OGS-2 completed its installation and began initial field calibration of its adaptive optics system against stars. The LCRD project also worked towards demonstrating bidirectional optical communications relay services between geosynchronous orbit and Earth. SCaN is currently developing two laser communications terminals for crewed spaceflight missions. The Integrated LCRD Laser User Modem and Amplifier Terminal (ILLUMA-T) is scheduled to fly on the ISS, and the "Optical to Orion" (O2O) terminal is scheduled to fly on Orion during Exploration Mission (EM) 2. Both terminals passed their System Requirements Reviews in August 2017.

SCaN worked with the European Space Agency (ESA) to demonstrate navigation protocols using Europe's Galileo global navigation satellite system on the SCaN TestBed. The SCaN TestBed on ISS,

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

which recently celebrated five years on orbit, tests various software defined radio technologies to demonstrate cognitive radios that learn from experience and improve performance autonomously.

The Standards project developed specifications for a wireless local area network protocol, supporting communications for both human and robotic activities on planetary surfaces. SCaN worked in 2017 with the NTIA Policy and Plans Steering Group to help identify Federal spectrum for auction and repurpose for commercial mobile broadband. The Spectrum Management Office, working directly with mission projects, completed operational certification of spectrum support for various human spaceflight mission elements, Science Mission Directorate (SMD) missions, and small satellite missions across the Agency.

WORK IN PROGRESS IN FY 2018

SCaN will continue defining NASA's next generation network architecture, incorporating new capabilities for higher bandwidth, on-demand services, Delay/Disruption Tolerant networking (DTN), and autonomous navigation. SCaN will work with the Exploration programs to define the communication and navigation capabilities needed to support future exploration. Responses to several RFIs from industry will be evaluated and used to formulate innovative commercial partnerships as part of a broader programmatic approach for the Next Generation architecture.

SCaN will also continue the infusion into its operations of new technologies that could enable significant reductions in system acquisition and operations cost while improving network flexibility, scalability, and security. In accordance with the NASA Transition Authorization Act of 2017, NASA is developing a plan to meet the Administration's projected space communications and navigation needs for low Earth orbit and deep space operations for the next 20 years. Towards that effort, NASA engaged with the interagency and industry communities through a variety of venues during late FY 2017 and continuing into FY 2018.

SCaN will continue to work with STMD (which will be part of the new ER&T organization) on LCRD. Both OGS-1 and OGS-2 will begin their integration and testing work, which are key milestones for completion. Preliminary design reviews (PDR) for both ILLUMA-T and the O2O terminal will be completed as well.

SCaN will continue to partner with the SMD and STMD (which will be part of the new ER&T organization) on Deep Space Optical Communication (DSOC) to increase data rates by a factor of 10-100, without increasing mission burden in mass, volume, power and/or spectrum. The SMD Discovery Psyche Mission was selected to demonstrate this DSOC terminal technology; it is scheduled to launch in 2022. SCaN completed the System Readiness Review and will complete detailed design of uplink and downlink stations and begin fabrication to support an operational readiness date in late FY 2021 for the ground terminal.

The U.S. Air Force will host the Deep Space Atomic Clock (DSAC) demonstration unit as part of the U.S. Air Force's Space Test Program 2 mission aboard a SpaceX Falcon 9 Heavy, scheduled for launch in June 2018. DSAC is a mercury ion clock that is an order of magnitude more stable than the current GPS clocks and will demonstrate its functionality and utility for one-way-based navigation for up to a year of operations. The clock will make use of GPS satellite signals to demonstrate precision orbit determination and confirm its performance.

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

In October 2017, SCaN held a NASA Space Communication Data Standard Webinar for the U.S. industry with 53 participants from NASA and 17 U.S. companies to engage the U.S. commercial sector in space communication data standards, including space-to-ground, ground-to-space, and space-to-space. A standard is also being developed for data exchanged between onboard software applications and hardware devices to enable missions to exchange electronic interface specifications across agencies.

SCaN's Spectrum Management Office is currently securing continued use beyond EM-2 of wideband S-band telemetry for SLS which will require agreements from DoD, the Aerospace and Flight Test Radio Coordinating Council, and NTIA before operational certification. The Spectrum Office continues to work with the Commercial Crew Program and other agencies to coordinate spectrum use for commercial vehicles transporting crew to ISS. Further, NASA is performing compatibility analyses with on-going spectrum sharing initiatives to enable bi-directional access to spectrum between the U.S. Government and the commercial sector.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

SCaN will conduct an architecture review for the initial increments of the Next Generation Architecture. The plan incorporates new capabilities for higher bandwidth, on-demand services, Delay/Disruption Tolerant networking, and autonomous navigation through the infusion of new technologies, such as optical communications. These new technologies combined with innovative business approaches are expected to enable significant reductions in system acquisition and operations cost while improving network flexibility, scalability, security, and performance.

SCaN will continue its work with Exploration Research and Technology on LCRD with integration and test activities beginning in FY 2018. SCaN will complete both OGS-1 and OGS-2 to support the LCRD launch in FY 2019. The ILLUMA-T and Orion EM-2 O2O projects will complete their Critical Design Reviews (CDR) and begin payload integration and test. The DSOC optical ground station project will complete its PDR, noting that it is about 10 months after the flight hardware PDR as supported by STMD (the new ER&T organization).

Through participation in the Interagency Operations Advisory Group and Consultative Committee for Space Data Systems, SCaN will continue international coordination of space communication and navigation compatibility and interoperability, as well as the development of internationally interoperable space communication and data system standards. NASA missions use internationally interoperable standards to lower the life cycle costs and risks, and provide innovative capabilities for current and future missions. Key progress is planned for Optical and Space Internetworking standards which may be used in NASA’s Next Generation Space Communications and Exploration Architectures.

As NASA's Spectrum Manager, SCaN will continue to participate in domestic and international meetings to ensure interference-free use of the electromagnetic spectrum supporting requirements for NASA's current and future missions. SCaN will focus on planned agenda items at the World Radiocommunication Conference in FY 2020, and working within the U.S. Delegation, will seek to ensure continued access to the radiofrequency spectrum supporting NASA's mission requirements, the U.S. Government space interests, and the U.S. commercial space community. In addition, SCaN will continue to coordinate spectrum use for all domestic and international deep space missions, and NASA near-Earth missions.

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

Project Schedule

The table below includes significant Space Communication Support milestones in FY 2018 and FY 2019.

Date	Significant Event
FY 2018 - Q1	DSOC passes Systems Readiness Review
FY 2018 - Q1	ILLUMA-T and O2O pass Systems Requirements Reviews
FY 2018 - Q3	DSAC Launch
FY 2018 - Q3	LCRD OGS-2 System Integration Review
FY 2018 - Q4	PDRs for ILLUMA-T and O2O laser terminals for ISS and Orion EM-2
FY 2018 - Q4	DSOC Flight Terminal Preliminary Design Review
FY 2019 - Q2	LCRD Operations Readiness Review
FY 2019 - Q3	DSOC Ground Terminal Preliminary Design Review
FY 2019 - Q3	OGS-2 ORR
FY 2019 - Q4	LCRD launch

Project Management & Commitments

The SCaN program office at NASA Headquarters manages Space Communications Support functions.

Element	Description	Provider Details	Change from Formulation Agreement
Space Communications Support	Provides critical communication and navigation architecture planning, systems engineering, technology development, standards development and management, spectrum management, and policy and strategic communications for NASA	Provider: NASA Responsible Center: HQ	N/A

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

Acquisition Strategy

Space Communications Support functions use multiple small contracted efforts, most of which are support services functions. Studies are in progress to assess alternate acquisition approaches for the next generation architecture, including collaborative research and development agreements, as well as public-private-partnerships and/or other commercial acquisition mechanisms to develop new optical communications technologies.

MAJOR CONTRACTS/AWARDS

Space Communications Support does not have any major contracts planned at this time.

HUMAN SPACE FLIGHT OPERATIONS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	123.1	--	135.4	136.4	136.4	145.9	147.8

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Astronaut Candidate Class of 2017

The Human Space Flight Operations (HSFO) Program supports the training, readiness, and health of crewmembers before, during, and after each spaceflight mission to the International Space Station (ISS). All crews on board the ISS have undergone rigorous preparation, which is critical to mission success. Within the HSFO program, the Space Flight Crew Operations (SFCO) element provides astronaut selection and training while the Crew Health and Safety (CHS) element manages all aspects of astronaut crew health.

To prepare for the next step in human space exploration, the Agency is developing the transportation system that will carry crew to destinations beyond Earth's orbit. NASA must also prepare the human system for living and working for extended periods in the hostile environment of space. As astronauts travel further from Earth, many different issues will arise and need investigating. What health risks will astronauts face and how are they resolved? What type of training will crews need to prepare for months of travel in the harsh space environment? How will they deal with medical emergencies or technical anomalies when Earth is no longer within reach? CHS, in collaboration with NASA's Office of Chief Health and Medical Officer and the Human Research Program (HRP), answers these and other questions to ensure crew health, safety, and mission success. SFCO and CHS are responsible for astronaut training, readiness, and health while HRP funds research development of human health and performance countermeasures, knowledge, and technologies that enable safe, reliable, and productive human space exploration.

HUMAN SPACE FLIGHT OPERATIONS

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

SFCO continued to provide astronaut training to support the crewed test flights of the first commercial crew vehicles. To train for the test flights, crews are using part-task trainers. The part-task trainers, each large enough for one person at the controls and programmed to run through all the phases of a mission, are part of a suite of cloud-based and hands-on trainers that Boeing has built to prepare astronauts and mission controllers. In addition, astronaut training continued using a full-scale simulator for the Boeing CST-100 Starliner. The Starliner, along with the SpaceX Crew Dragon are the two new vehicles being developed in support of the Commercial Crew Program.

In October 2016, SFCO finished the first round of interviews as part of the selection process for the astronaut candidate (ASCAN) class of 2017. From the first round of 120 interviewees, 50 individuals were selected in January 2017 for another round of evaluations. NASA completed the second round of interviews in May and announced the 12 final astronaut candidates selected in June 2017. The new class reported to JSC in August to begin formal training. This training and evaluation period will last between one-and-a-half to two years to develop the basic knowledge and skills required for specific mission training upon assignment for a spaceflight on ISS, Russian Soyuz spacecraft, a Commercial Crew partner’s spacecraft, and/or NASA’s Orion spacecraft. CHS provides medical testing and evaluation of the candidates as part of the selection process.

Spaceflight readiness training continues throughout an astronaut’s career to prepare them for living and working in space as well as responding to any emergency scenarios, including high-performance aircraft training. SFCO aircraft logged over 2,700 hours in 2017 in support of crew training. As part of SFCO's responsibility for maintaining these planes, SFCO began planned structural upgrades to the 55-year-old T-38 spaceflight readiness training aircraft to replace critical parts that exhibit stress corrosion cracking. In addition, the Super Guppy aircraft, NASA’s over-sized cargo transporter, received a floor modification in order to transport the Orion Crew Service Module.

CHS conducted physical, behavioral, return, and reconditioning health support for returning ISS Expeditions and provided crew health support for astronauts training to fly on commercial crew vehicles. In addition, CHS provided clinical certification and mission support for active astronauts departing or returning to the ISS. CHS accumulated and archived crew health and safety data for use by both the medical and research communities. Congress passed the To Research, Evaluate, Assess, and Treat Astronauts Act (TREAT) on March 21, 2017. CHS worked to meet the demands of the NASA Transition Authorization Act of 2017 language – work that will continue into FY 2018.

In FY 2017, HRP worked to finish transitioning the Integrated Medical Model 4.0 to CHS. The Integrated Medical Model is a computer-based tool that is a central part of NASA risk management activity from the crew medical and mission performance perspective. The model uses the best available evidence from spaceflight, terrestrial medical literature, spaceflight analog studies, and other sources of information to perform a modeled simulation that allows traceable answers to questions for both current and future mission planning. This unique capability merges expertise in clinical medicine, epidemiology, and probabilistic risk assessment to promote astronaut health and performance during spaceflight missions.

HUMAN SPACE FLIGHT OPERATIONS

CHS updated the Astronaut Radiation Exposure and Analysis Database to incorporate exposure data from multiple missions to ISS. CHS worked with HRP on progress towards developing mitigation strategies for astronaut exposure and protection from solar and galactic radiation during space missions. Mitigation of solar and galactic radiation beyond the protection of the Earth's atmosphere is an occupational and safety concern particularly for long duration human spaceflight. CHS also coordinated with HRP in other areas, such as behavioral health, supporting research to reduce the risk of behavioral health challenges. Collaborated closely with HRP to add new capability to our current on-orbit tool in order to better assess subtle fluctuations in cognition that are relevant to task performance. This tool is designed to assess negative effects on cognitive functioning from head trauma, carbon dioxide, loss of sleep and fatigue, payload toxins, or abnormal environmental events.

WORK IN PROGRESS IN FY 2018

In FY 2018, SFCO will continue to support flight crew training requirements and mission operations for test flights of the SpaceX Dragon and Boeing Starliner. SFCO will also continue training the 2017 Astronaut Candidate (ASCAN) class.

To support ISS mission increments, CHS will provide pre-flight, in-flight and post-flight medical, behavioral health management, and physical conditioning services to NASA crewmembers. In FY 2018, CHS will also track and monitor emerging hazards for NASA's new flight programs, Commercial Crew and Orion. For example, CHS will evaluate progress on radiation environmental data to inform future Exploration Mission crewed flights. The program will provide preflight and operations support to test flights of SpaceX Dragon and Boeing Starliner commercial spacecraft carrying NASA astronauts. CHS will also expand its Lifetime Surveillance of Astronaut Health program for former crew members to better understand the long-term health consequences of space exploration. The evidence acquired through this program not only benefits the health of former astronauts, but also helps make future spaceflight missions safer.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

In FY 2019, SFCO will continue to support ISS flight crew training requirements and mission operations for Russian Soyuz spacecraft launch vehicle and U. S. commercial spacecraft, the SpaceX Dragon and Boeing Starliner. ISS mission operations support will increase with the change in crew size from six to seven. SFCO will complete training for the 2017 ASCAN class and, will work with the Agency to decide whether to recruit a FY 2020 ASCAN class. SFCO will continue operation and maintenance of support aircraft.

To support mission increments, CHS will provide preflight training, medical, behavioral health management, physical conditioning and baseline occupational surveillance. In addition, CHS will provide preflight through post flight medical, behavioral and physical conditioning support of NASA crewed SpaceX Dragon and Boeing Starliner commercial spacecraft. Test personnel and medical guidance will be provided to support the EM-2 mission. CHS will implement the TREAT Act, to include expanding the Lifetime Surveillance of Astronaut Health program for former crew members to better understand long-term health consequences of space exploration. Data analytics capabilities will be expanded to support medical diagnostic capabilities for exploration missions including gateway missions.

Program Elements

SPACE FLIGHT CREW OPERATIONS (SFCO)

SFCO directs and manages flight crew activities, selects astronaut candidates, recommends flight crew assignments, and maintains all aircraft, including the fleet of T-38 high performance aircraft used for astronaut spaceflight readiness training. In addition, SFCO ensures that spaceflight readiness training requirements continue to support ongoing ISS operations, planned exploration, and commercial development.

SFCO is also responsible for all astronaut training. As part of its annual planning, the project ensures astronaut training is consistent with ISS and Exploration manifest requirements. The number of spacecraft seats U.S. astronauts will fill in the next four years of human spaceflight determines the manifest requirement. The manifest includes ISS via Soyuz, as well as projected Commercial Crew and Orion/SLS development flights. Today, it takes three years from the decision to select a new astronaut class until the process is completed. Once selected, new astronauts must complete 12-18 months of training for eligibility and then 30 months of ISS training before a new astronaut is qualified for an ISS mission. Astronaut training activities, overseen by SFCO include launch and landing operations, ability to respond in an emergency/high-stress environment, high performance aircraft operations skills, flight vehicle maintenance, payload and science experiment operator skills, extravehicular activities, Russian language skills, robotics (including free-flier capture), and ISS systems knowledge.

CREW HEALTH AND SAFETY (CHS)

CHS enables healthy and productive crew during all phases of spaceflight missions, implements a comprehensive astronaut occupational health care program, and works to prevent and mitigate negative long-term health consequences from exposure to the spaceflight environment. Using HRP research and other findings, CHS implements changes to astronaut occupational health protocols to ensure crew health and safety. CHS also medically assesses astronaut candidates as part of the selection process. In this collaboration, HRP concentrates on the research aspects of crew health, whereas CHS focuses on implementing the research results and mitigation plans into occupational health protocols. As research continues on ISS through 2024, CHS is actively seeking new approaches to expand the research findings that can be used to improve NASA health protocols, including collaborative opportunities with other Federal agencies and academia.

CHS is also responsible for maintaining the health of active astronauts during non-mission periods, focusing on three aspects of health care: preventive care, risk factor management, and long-term health monitoring. CHS integrates and coordinates information relevant to the human health before, during, and after spaceflight. CHS documents and assesses all emerging health risks, such as Spaceflight Associated Neuro-ocular Syndrome (SANS; previously referred to as Visual Impairment and Intracranial Pressure (VIIP) Syndrome). CHS has continued to collaborate with several non-NASA organizations, including the National Academies, to inform the risk decisions associated with long duration and exploration missions.

Program Schedule

Date	Significant Event
Mar 2018	Treat Act Costs and Implementation – Completion of Congressionally requested independent cost analysis.

Program Management & Commitments

Program Element	Provider
SFCO	Provider: SFCO Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): None
CHS	Provider: CHS Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): None

Acquisition Strategy

The section below identifies the current contract(s) that support SFCO and CHS.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Aircraft Logistics, Integration, Configuration and Engineering	Yulista Tactical	Ellington Field, Houston, TX, El Paso, TX
Human Health and Performance Contract	KBR Wyle	Houston, TX

HUMAN SPACE FLIGHT OPERATIONS

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	National Council on Radiation Protection and Measurements (NCRP)	Nov 2014	The NCRP reviewed NASA Radiation Protection Standards for crew member exposure to spaceflight radiation	NCRP Commentary Report 23: Radiation Protection for Space Activities: Supplement to Previous Recommendations	
Performance	NCRP	Feb 2016	The NCRP conducted a phase one review of potential central nervous system (CNS) effects from radiation exposure during space activities.	NCRP Commentary Report 25: Potential Central Nervous System Risks Following Space Radiation Exposure	Phase II in progress

LAUNCH SERVICES

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**85.7**	**--**	**86.6**	**88.6**	**88.6**	**88.6**	**88.6**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

August 18, 2017: A United Launch Alliance Atlas V rocket lifts off from Space Launch Complex 41 at Cape Canaveral Air Force Station in Florida, with NASA's Tracking and Data Relay Satellite, TDRS-M. TDRS-M is the latest spacecraft destined for the agency's constellation of communications satellites that allows nearly continuous contact with orbiting spacecraft ranging from the International Space Station and Hubble Space Telescope to the array of scientific observatories.

The Launch Services Program (LSP) provides customers with an Earth-to-space bridge for science and discovery through access to space. Utilizing commercially-available domestic launch services, LSP has provided affordable and reliable space access for uncrewed science, exploration, communication, weather forecasting, and technology development spacecraft for over 19 years. NASA and civil sector missions need these launch services to get into space and begin their critical work.

Acting as a launch system technical expert, LSP matches NASA and other civil sector government spacecraft with commercially-available launch services through a competitive acquisition process. Starting with pre-mission planning and continuing through the spacecraft's post-launch phase, LSP works with the spacecraft mission team and the commercial launch vehicle provider to accomplish the required mission integration and mission assurance activities to maximize the probability for mission success.

In addition to acquiring the commercial launch service, LSP arranges pre-launch spacecraft processing facility support, and communications and telemetry during ascent for its customers. LSP offers insight into the commercial launch vehicle industry, tracks lessons learned to identify and mitigate risks for future managed launches, and certifies the readiness of new commercial launch vehicles for NASA and other civil sector uncrewed spacecraft. The program also conducts engineering analyses and other technical tasks to maximize launch success for every assigned payload.

LAUNCH SERVICES

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

Three major payloads were successfully launched utilizing LSP-acquired services:

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Nov 2016 Cape Canaveral Air Force Station	Atlas V	Geostationary Operational Environmental Satellite (GOES)-R	NOAA, NASA SMD	First in a series of next generation geostationary weather satellites that will provide continuous imagery and atmospheric measurements of Earth's Western Hemisphere and space weather monitoring.
Dec 2016 Cape Canaveral Air Force Station	Pegasus XL	Cyclone Global Navigation Satellite System (CYGNSS)	NASA SMD	Measure ocean surface winds throughout the life cycle of tropical storms and hurricanes, to facilitate better weather forecasting.
Aug 2017 Cape Canaveral Air Force Station	Atlas V	Tracking and Data Relay Satellite (TDRS)-M	NASA HEOMD	Provide crosslink communications capability between control and data processing facilities on the ground, and Earth-orbiting spacecraft such as the Hubble Space Telescope, ISS, and dozens of unmanned scientific satellites.

LSP's customers own and manage the payload mission objectives described above.

LSP continued efforts to expand the selection of available launch vehicles, working across industry to support commercial space sector growth by providing competitive opportunities to U.S. providers.

LAUNCH SERVICES

LSP acquired launch services for two future science missions:

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Apr 2021 Vandenberg Air Force Base	Falcon 9 Full Thrust (F9 FT)	Surface Water & Ocean Topography (SWOT)	NASA SMD	Brings together two communities focused on better understanding of the world's oceans and its terrestrial surface waters. SWOT will make the first global survey of Earth's surface water, observe the fine details of the ocean's surface topography, and measure how water bodies change over time
Jul 2021 Vandenberg Air Force Base	Atlas V	Joint Polar Satellite System (JPSS)-2	NASA SMD	Gather data on a wide range of Earth's properties, including the atmosphere, clouds, radiation budget, clear-air land and water surfaces, and sea surface temperature

LSP's customers own and manage the payload mission objectives described above.

In May 2017, United Launch Services (ULS) successfully completed "Category 3" certification of the Delta IV Heavy launch vehicle with LSP in preparation for the Parker Solar Probe (formerly Solar Probe Plus) mission. In addition, LSP continued to support the certification activities of Space Exploration Technologies Inc. (SpaceX) for the Falcon 9 "Full Thrust" launch vehicle, and is conducting preliminary activities that would support the eventual certification of the Orbital ATK Antares 230 as well as proposed future launch vehicles such as the ULA Vulcan, the Orbital ATK Next Generation Launcher, and the Blue Origin New Glenn launch vehicles. Achieving certification enhances NASA's understanding of commercially built launch vehicles and enables LSP to better identify and manage launch risks. Certification also enhances competition as it results in multiple qualified launch vehicles and launch providers, which in turn promotes cost control.

LSP participated in the SpaceX-led Accident Investigation Team (AIT) for the Falcon 9 anomaly that occurred on September 1, 2016, when the rocket exploded on the launch pad during a routine prelaunch fueling operation on a non-NASA mission to launch the commercial communications satellite Amos 6. AIT was comprised of members from SpaceX, Federal Aviation Administration (FAA), NASA, U.S. Air Force (USAF), and industry experts. The SpaceX investigation has been completed and corrective actions are being implemented. A separate LSP-led independent review for the September 1, 2016, Falcon 9 anomaly is still on-going in an effort to find the definitive set of conditions that caused the anomaly. The LSP-led investigation team continues to make significant progress and has begun testing of the composite overwrapped pressure vessels (COPVs). One of the Falcon 9 upper stage COPVs, while undergoing helium loading/pressurization during upper stage liquid oxygen loading, appears to be where the ignition occurred that led to the explosion.

NASA and LSP continue to partner with several universities and NASA Centers to launch small research satellites through the CubeSat Launch Initiative (CSLI), which provides rideshare opportunities for small satellite payloads to fly on upcoming launches when space is available. These partnerships have provided regular educational opportunities for students in science, technology, engineering, and mathematics disciplines, thereby strengthening the Nation's future workforce. To date, CubeSats have been selected from 38 states across the United States, with 49 missions launched and 46 manifested on NASA, National Reconnaissance Office, USAF, and commercial missions. In FY 2017 six CSLI cubesats were launched.

WORK IN PROGRESS IN FY 2018

LSP provides expertise and active launch mission management for over 40 NASA scientific spacecraft missions in various stages of development. In January 2018, SpaceX successfully completed "Category 2" certification of the SpaceX Falcon 9 "Full Thrust" with LSP which supports the launch of the NASA Transiting Exoplanet Survey Satellite (TESS) mission in March 2018. In FY 2018, the program will continue to acquire new launch services for future NASA missions. Seven science missions and two Venture Class Launch Services (VCLS) missions are planned for launch in FY 2018. The program has recently competitively awarded launch service contracts for the NASA Science Mission Directorate's Sentinel 6A and Landsat 9 missions for launch aboard a Falcon 9 and an Atlas V, respectively.

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Nov 2017 Vandenberg Air Force Base	Delta II	JPSS-1	NASA SMD	First of three satellites that will provide global environmental data used in weather prediction models for forecasts, and scientific data for climate monitoring which will increase timeliness and accuracy of forecasts of climate and weather events, thus reducing potential loss of human life and property
Mar 2018 Cape Canaveral Air Force Station	Atlas V	GOES-S	NOAA, NASA SMD	Follow on mission in a series of satellites that will provide continuous imagery and atmospheric measurements of Earth’s Western Hemisphere and space weather monitoring.
Mar 2018 Cape Canaveral Air Force Station	Falcon 9 "Full Thrust"	TESS	NASA SMD	Space telescope designed to survey the brightest stars near the Earth utilizing an array of cameras. The all-sky survey will study the mass, size, density and orbit of a large cohort of small planets, including a sample of rocky worlds in the habitable zones of their host stars.
May 2018 Vandenberg Air Force Base	Atlas V	Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight)	NASA SMD	Will address fundamental issues of planet formation and evolution with a study of the deep interior of Mars.
Jun 2018 (Under Review) Cape Canaveral Air Force Station	Pegasus XL	Ionospheric Connection Explorer (ICON)	NASA SMD	A suite of instruments designed to explore the mechanisms controlling environmental conditions in space and how they are modified by weather on the planet

LAUNCH SERVICES

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Jul 2018 Cape Canaveral Air Force Station	Delta IV-Heavy	Parker Solar Probe	NASA SMD	Flying into the Sun's atmosphere (or corona), for the first time, the Parker Solar Probe will employ a combination of in situ measurements and imaging to achieve the mission's primary scientific goal: to understand how the Sun's corona is heated and how the solar wind is accelerated.
Sep 2018 Vandenberg Air Force Base	Delta II	Ice, Clouds, and Land Elevation Satellite (ICESat)-2	NASA SMD	Second generation satellite used to collect altimetry data of the Earth's surface to measure ice sheet mass balance, cloud and aerosol heights, while also generating an estimate of global vegetation biomass.

LSP's customers own and manage the payload mission objectives described above.

VCLS contracts for CubeSat satellites foster a commercial launch market dedicated to flying small satellite payloads by serving as an alternative to the current rideshare approach in which one or more CubeSats takes advantage of excess payload capacity on a rocket whose primary mission is to launch a larger satellite. Under the VCLS contracts, Rocket Lab USA's Electron launch vehicle and Virgin Orbit's LauncherOne are both scheduled to launch in the first half of FY 2018. Each launch will carry multiple CubeSats to low Earth orbit.

LSP will continue work towards certifying new commercial launch vehicles to launch high-value payloads. Certification of the SpaceX Falcon 9 "Full Thrust" is nearing completion.

Along with full end-to-end launch service management, the program continues to offer advisory support, expertise, and knowledge to NASA programs and projects utilizing launch services not procured and managed by LSP. The program is currently providing these advisory services to several programs and missions, including:

- ISS Cargo Resupply Service missions;
- Commercial Crew Program; and
- SMD's Gravity Recovery and Climate Experiment Follow-On (GRACE-FO), James Webb Space Telescope (Webb), and NASA-Indian Space Research Organization Synthetic Aperture Radar (NISAR) missions

KEY ACHIEVEMENTS PLANNED FOR FY 2019

LSP will continue launch service acquisition activities necessary to support NASA and other approved government missions, and will continue providing launch related mission support to over 40 NASA scientific spacecraft missions in various development phases. LSP will also continue work towards certifying new commercial launch vehicles to launch high value payloads, as needed.

Program Management & Commitments

Program Element	Provider
Expendable Launch Vehicle (ELV) Launch Services	Provider: United Launch Services (ULS), Orbital ATK, SpaceX, Rocket Lab USA, Virgin Orbit Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): N/A

ACQUISITION STRATEGY

LSP's acquisition strategy was created for the original NASA Launch Services (NLS) contracts for procuring ELV launch services from domestic commercial launch service suppliers. To meet the needs of science and technology customers who typically spend three to seven years developing a spacecraft mission, NASA created a contractual approach providing multiple competitive launch service options to cover small, medium, intermediate and heavy-sized missions. The follow-on contract mechanism, known as NLS II, has similar contract features, such as not-to-exceed prices; indefinite delivery/indefinite quantity contract terms; and firm-fixed-price, competitive, launch service task-order-based acquisitions. The NLS II ordering period has been extended to June 30, 2025. To ensure active ongoing competition for NASA customers and encourage new launch capability development through these long-term contracts, NASA provides annual opportunities to U.S. industry to add new commercial launch service providers and/or launch vehicles to the active contract.

LSP is also able to contract separately from the NLS contract mechanism if such an approach is necessary to meet a particular mission or customer need. For instance, for the Parker Solar Probe mission funded by NASA SMD, the launch service was competed outside and separate from the NLS II contract due to the special needs of that mission. In addition, the VCLS awards for very small launch vehicles were conducted outside and separate from the NLS II contract in order to provide more flexibility to the new small-class launch providers.

NASA has also made efforts to provide a complete launch service, including payload processing at the launch site. LSP uses firm-fixed-price indefinite delivery/indefinite quantity (IDIQ) contracts for commercial payload processing capabilities on both the east and west coasts. The Payload Processing Facility contracts ordering period expired in December 2017. The East Coast Commercial Payload Processing Contract-3 (ECCPP-3) was awarded in April with a period of performance ending April 2022. The West Coast Commercial Payload Processing Contract-2 (WCCPP-2) will be re-competed in Spring 2018, with anticipated award of the IDIQ in late summer 2018.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
SPP	ULS, LLC	Centennial, CO
Venture Class	Virgin Orbit, Rocket Lab USA	Long Beach, CA Los Angeles, CA

LAUNCH SERVICES

Element	Vendor	Location (of work performance)
NLS-II-U	ULS, LLC	Centennial, CO
NLS-II-S	SpaceX	Hawthorne, CA
NLS-II-O	Orbital ATK Corporation	Dulles, VA
Payload Processing Facility	Astrotech Space Operations	Titusville, FL
Payload Processing Facility	Astrotech Space Operations	Vandenberg Air Force Base, CA
Integrated Processing Facility	Spaceport Systems International	Vandenberg Air Force Base, CA
Expendable Launch Vehicle Integrated Support (ELVIS) 2/3	a.i. Solutions, Inc.	Lanham, MD

INDEPENDENT REVIEWS

NASA has scheduled the LSP Program Implementation Review (PIR) in CY 2019.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PIR	Standing Review Board (SRB)	May 2014	Life Cycle Review	The SRB found LSP is a successful program with a strong technical and management team representing NASA's core competency, demonstrating exceptional performance with a 97.4 percent launch success record. The SRB recommended continuation of LSP operations as currently performed.	2019

This 2019 milestone for LSP will be assessed by the HEOMD Associate Administrator and a determination made whether or not a PIR is required, or if it can be delayed another two years. The 2019 milestone is also subject to change depending on LSP's manifest/launch schedule for that year.

Historical Performance

LSP managed ELV Missions from inception through FY 2016.

Launch Vehicle Configuration	Provider	Number of Launches	Successful Launches	Unsuccessful Launches
Athena	Lockheed Martin/Alliant Techsystems	1	1	0
Atlas IIA	Lockheed Martin	5	5	0
Atlas IIAS	Lockheed Martin	1	1	0
Atlas V	Lockheed Martin ULS	2 16	2 16	0 0
Delta II	Boeing Launch Services ULS	27 14	27 14	0 0
Falcon 9 v1.1	Space X Launch Services	1	1	0
Pegasus Hybrid	OSC	1	1	0
Pegasus XL	OSC	15	15	0
Taurus XL	OSC	2	0	2
Titan II	Lockheed Martin	3	3	0

ROCKET PROPULSION TEST

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**43.7**	**--**	**47.6**	**47.6**	**47.6**	**47.6**	**47.6**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

RPT continues to support SLS RS-25 engine testing on the A-1 test stand at Stennis Space Center in Mississippi.

Developing and testing rocket propulsion systems are foundational to spaceflight. Whether the payload is a robotic science experiment or a crewed mission, the propulsion system must be safe, and reliable. A rigorous engine test program is a critical component of any rocket propulsion development activity.

NASA's Rocket Propulsion Test (RPT) program maintains and manages a wide range of facilities capable of ground testing rocket engines and components under controlled conditions. This test infrastructure includes facilities located across the United States and provides a single entry point for any user of the rocket test stands. RPT retains a skilled workforce, capable of performing tests on all modern-day rockets including supporting complex rocket engine development. RPT evaluates customer test requirements and desired outcomes, minimizing test time and costs. It also streamlines facility usage and eliminates redundant capabilities by closing and consolidating NASA's rocket test facilities.

RPT is NASA's implementing authority for rocket propulsion testing. It approves and provides direction on test assignments, capital improvements, and facility modernization and refurbishment. RPT integrates multi-site test activities, identifies and protects core capabilities, and develops advanced testing technologies.

The Agency has designated RPT as the NASA representative for the National Rocket Propulsion Test Alliance (NRPTA) - an inter-agency collaboration with the Department of Defense (DoD) to facilitate efficient and effective use of the Federal Government's rocket propulsion test capabilities. The RPT Manager serves as a co-chair of the NRPTA Senior Steering Group, and appoints NASA's alliance co-chair. The alliance co-chair position is a rotational appointment chosen from primary center representatives of RPT's management board.

For additional programmatic information, go to: https://rockettest.nasa.gov/

ROCKET PROPULSION TEST

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

During FY 2017, RPT safely performed 590 tests of rocket engines and components at various levels of thrust. Hot fire test time totaled 18,426 seconds and 52 hours of propulsion system thermal vacuum testing. These tests were completed with only seven facility-caused test delays resulting in a 98.8% test stand availability, exceeding the Agency Performance goal of 90% as defined in Space and Flight Support (SFS) section 15-1 of the NASA Management and Performance report.

In FY 2017, RPT performed seven RS-25 engine tests on the Stennis Space Center (SSC) A-1 test stand. The seven tests accounted for 2,880 seconds of hot fire test time in a multi-year effort necessary to certify the engine for use on Space Launch System (SLS) core booster stage, which is required to support Exploration Mission-1 (EM-1), the first flight of SLS, and other exploration goals. Other test activities included testing for SpaceX, Aerojet Rocketdyne, and numerous internal, DoD and commercial research and development projects such as the U.S. Air Force (USAF) designed and developed Hydrocarbon Boost components, a critical effort to support the DoD objective of replacing the RD-180 engine used in the Atlas V launch vehicle. In addition to the USAF hydrocarbon program, NASA began performing Aerojet Rocketdyne hydrocarbon component testing on E-1 Test Stand, Cell 2.

At the Johnson Space Center White Sands Test Facility (WSTF), engineers conducted tests to support NASA's Commercial Crew Program, Aerojet Rocketdyne, the Missile Defense Agency engine and thruster program, the USAF Peacekeeper missile safing project, and hot fire test for the USAF Minuteman missile life extension program. RPT completed the refurbishment and reactivation of test stand 301 to support the Orion European Space Agency (ESA) Service Module and the construction of test stand 301A under a reimbursable task order with Boeing to conduct testing of the Crew Space Transportation (CST)-100 Service Module. On Test Stand 301 and 301A, RPT conducted the first tests of the Orion ESA Service Module and Boeing CST-100 Service Module, Launch Abort Engines, Reaction Control System and Orbital Maneuvering and Attitude Control thrusters. RPT also completed the refurbishment of the Large Altitude Simulation System (LASS) to support testing in a simulated high altitude space environment. The LASS maintains three test stands that provide a test start altitude of 115,000 feet.

At Glenn Research Center Plum Brook Station (GRC-PBS), RPT completed partial refurbishment of the In Space Propulsion Facility (ISPF), formerly referred to as the B-2 facility, for small propulsion systems up to 5,000 pounds of force (lbf) thrust. Following refurbishment, the ISPF validated the refurbished systems by performing 32 propulsion hot fire tests utilizing the Morpheus Lander for 750 seconds of hot fire and 52 hours of propulsion system-related thermal vacuum testing. The Morpheus hot fire tests were the first in the facility since 1999. In addition to Morpheus testing, RPT collaborated with the Glenn Research Facility to initiate a $5.5M project to refurbish the ISPF to perform propulsion related testing for systems up to 30k lbf with 300 seconds of run time.

At Marshall Space Flight Center, RPT continued testing rocket engine components manufactured using select laser melting and other additive manufacturing processes furthering the capabilities of both NASA and RPT.

ROCKET PROPULSION TEST

WORK IN PROGRESS IN FY 2018

Traditional testing philosophies and approaches are often considered too costly or time consuming in a budget and schedule constrained environment. A recent survey of internal and commercial test customers identified a need to have a low cost test capability for small components and engines (up to 15k lbf thrust). Test costs for these small items can exceed the cost to manufacture the test article, especially as developers are becoming more reliant on three-dimensional printing techniques which can reduce the costs of manufacturing small, complex items.

In 2018, the RPT Program Office is pursuing two initiatives to meet the changing needs of the propulsion systems developers. The first initiative is the development of two small test capabilities that can be operated with a minimum crew for development projects. The first of these test capabilities is the completion of a 5,000 lbf portable test rig. The second capability is a collaborative initiative utilizing early-career engineers from the participating RPT centers to design and develop a larger 10,000 lbf to 15,000 lbf thrust portable test capability. In addition to the actual design of a test capability, the early-career engineer initiative is designed to offer the participants an opportunity to gain critical experience in NASA's design processes, enhance communications skills, and build relationships amongst the centers.

The second initiative being pursued by the RPT Program Office is the RPT Benchmarking Initiative for Test Efficiencies and Affordability. The goal is to identify best practices that could be implemented at the participating RPT centers to identify tangible changes that could improve RPT operational efficiencies and decrease costs for the RPT Program Office and for test customers.

Results of the benchmarking initiative will be used to assist in planning activities by the RPT Program to ensure that efficient and affordable RPT test services are available to current and future test customers.

At SSC, RPT will continue testing the RS-25 engine in support of the SLS program. Development testing will continue for commercial companies seeking to test their engine systems on a reimbursable basis. These include performing tests on the USAF designed and developed Hydrocarbon Boost components for the RD-180 replacement project and Aerojet Rocketdyne hydrocarbon engine certification. Planned refurbishment and repair activities for critical enabling infrastructure include: continuing repair of SSC’s liquid oxygen and liquid hydrogen barges; upgrading high-pressure gas facility; replacing the E-Complex data acquisition system, replacing E-Complex high speed video equipment and activating the B-2 test stand to prepare for SLS core stage testing. SSC will also complete the construction of the joint Michoud Assembly Facility/SSC Consolidated Fluid Component Processing Facility.

The WSTF team will conduct propulsion system development and certification testing for the NASA Orion ESA Service Module and Commercial Crew Program Boeing CST-100 Service Module, Aerojet Rocketdyne, the Missile Defense Agency, USAF, and U.S. Navy.

MSFC will continue testing rocket engine technology improvements, including components constructed using select laser melting and other additive manufacturing processes that could lead to significant improvements in construction of these complex machines.

At GRC-PBS ISPF, RPT will continue improvements for future space exploration propulsion needs through Evolvable Cryogenics Project (eCRYO) in partnership with Space Technology Mission Directorate and will support research to reduce boil-off rate on large cryogenic upper stages with Structural Heat Intercept, Insulation and Vibration Evaluation Rig (SHIVER) in a simulated space environment (vacuum and thermal). In addition to the eCRYO project and facility upgrades, the ISPF will perform the thermal vacuum certification testing for the Commercial Crew Program SpaceX Dragon Crewed Capsule.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

Building on test results from previous years, RPT will continue to provide valuable propulsion data to the SLS and Orion programs as they prepare for EM-1 and EM-2. These tests will provide critical data to validate baseline designs, increase confidence in technical performance while reducing risks and achieving launch readiness on schedule. This ongoing effort will allow the program to assess design changes that could affect performance and improve safety. RPT personnel will continue hot fire testing the SLS RS-25 engine on SSC's A-1 test stand and preparing preparations for SLS core stage testing on the B-2 test stand. The core stage uses four RS-25 engines to propel the SLS core stage upon launch. In addition, RPT will continue preparations to test the SLS Exploration Upper Stage (EUS) on the newly refurbished B-2 test stand. RPT will also continue engine certification of the Aerojet Rocketdyne RS-68 liquid hydrogen/oxygen engine on the B-1 test stand.

At PBS, RPT will also provide data to SLS by completing the eCryo, SHIVER testing in a simulated space environment (vacuum and thermal) and perform critical environmental testing for SpaceX Dragon Crew Capsule.

At WSTF, RPT will continue testing activities for the Orion ESA Service Module and Boeing CST-100 Service Module. RPT will also continue providing critical propulsion test services to the Missile Defense Agency, Aerojet Rocketdyne and USAF test articles.

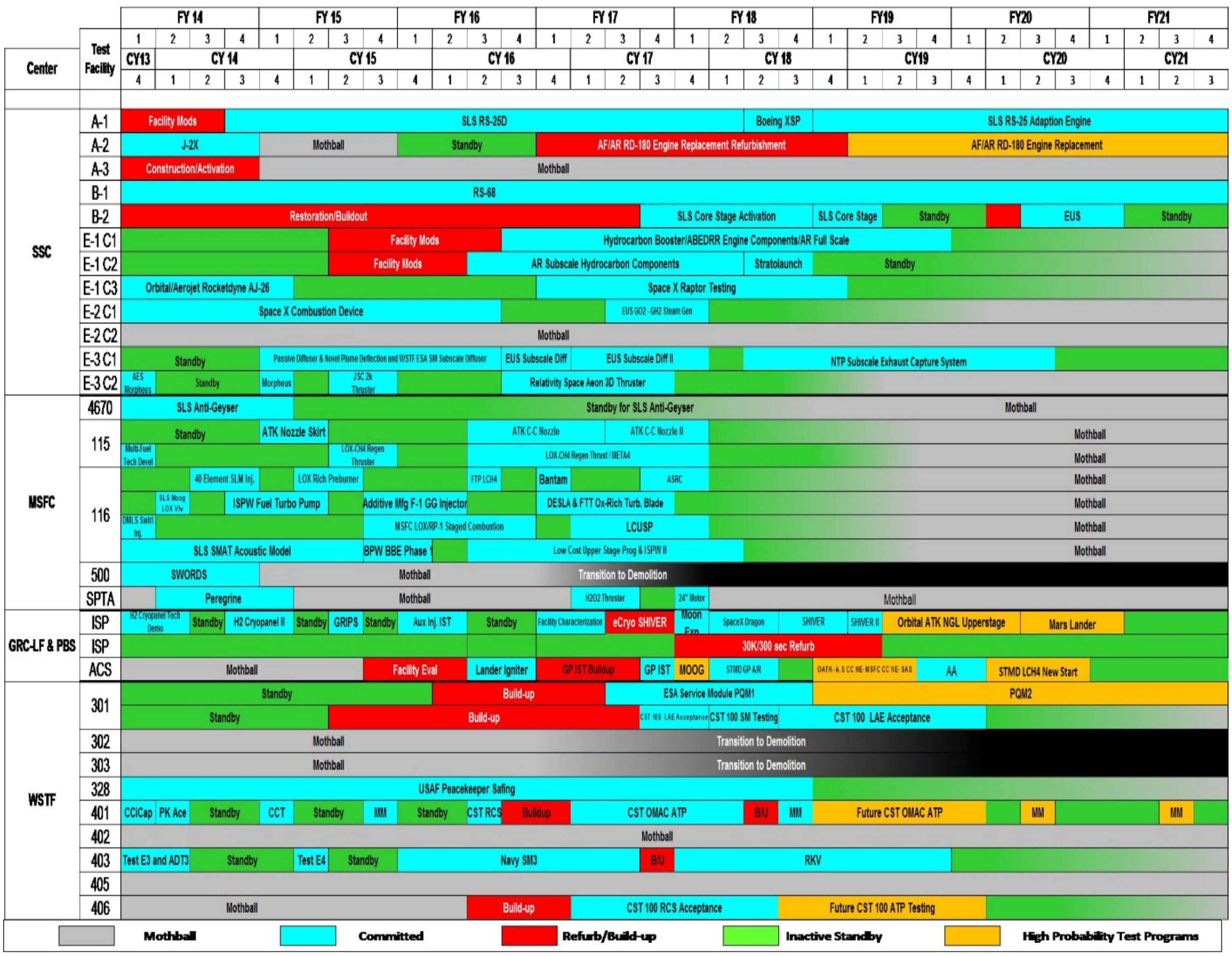
All RPT facilities and personnel will continue maintaining and modernizing these unique national assets which are critical for testing future space vehicles in a simulated space environment and ambient conditions.

ROCKET PROPULSION TEST

Program Schedule

The following chart shows past, current, and planned test campaigns at SSC, MSFC, GRC and WSTF rocket propulsion test facilities. The designations at the far left of the chart refer to the facility, the top of each chart shows time by quarter of fiscal and calendar year, and the key to the status of each facility is at the bottom.

Most test stands and facilities are scheduled 18 months in advance. Defining scope of work, selecting test stands and fuel, and estimating labor and total cost to customers is a complex process that can take 18 to 36 months. RPT is working now with internal and external customers to design testing programs for FY 2019 and beyond.



INDEPENDENT REVIEWS

No reviews planned.

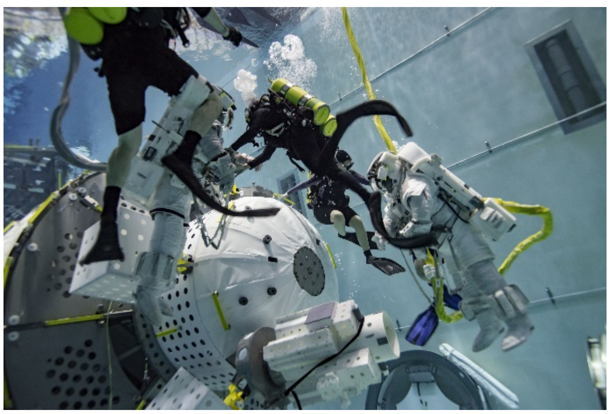
COMMERCIAL LEO DEVELOPMENT

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**0.0**	**--**	**150.0**	**150.0**	**175.0**	**200.0**	**225.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



NanoRacks Airlock Module mockup shown during a test run with astronauts in the Neutral Buoyancy Laboratory.

NASA is increasing efforts to develop a commercial space economy in low Earth orbit (LEO). Through the new Commercial LEO Development theme and program, NASA will support commercial partner development of capabilities that the private sector and NASA can use. Our efforts will focus on enabling, developing, and deploying commercial orbital platforms. The Budget proposes to end direct U.S. financial support for the International Space Station in 2025, after which NASA would rely on commercial partners for its low Earth orbit research and technology demonstration requirements. A primary purpose of the Commercial LEO Development program is to ensure that the United States has access to an orbital platform on which to conduct research and develop new technologies.

NASA is continuing to increase the cooperative use of the ISS to enable increased commercial investment and to transition to more public-private partnership models. The end goal is where NASA is one of many customers of a commercial market in LEO. Today on ISS, NASA has already enabled increased commercial investment and partnerships through the National Lab, agreements such as Nanoracks/Boeing Commercial Airlock, and contracts for commercial services once performed by NASA. The ISS, Commercial Crew, and Crew and Cargo programs will continue working together to solidify the important commercial successes that have been enabled by these programs and NASA's commercial and international partners.

However, NASA must also look beyond its current programs in order to secure the nation's future in LEO. The new Commercial LEO Development program will leverage the experience NASA and its private sector partners have with the construction, deployment, operations, and utilization of orbital platforms in order to ensure that the United States will continue to have access to LEO in the mid-2020s and beyond.

To achieve the Commercial LEO Development program's goals, its first activity will be to conduct an open competition for public and privately funded module(s) and/or platform(s) attached to the ISS or free-flying in LEO in FY 2018. NASA expects to make these awards in FY 2019. Several credible concepts for commercial LEO modules or capsules are possible. The competition that NASA proposes will allow interested parties to specify what support they desire from NASA. This could potentially include a subset or combination of the following options that could arise in the course of the discussions: a) access to a port on ISS; b) access to NASA's experience and capabilities through its unique workforce with expertise in the design, construction, launch, operations, and/or utilization of orbital platforms and c) financial support provided through the Commercial LEO Development program. Proposals will include market analysis and business plans. Legal, technical and programmatic issues require further study and coordination among the International Partners and commercial industry to provide a smooth transition.

If a winning proposal is to be attached to the ISS, NASA would make available in-kind contributions in the form of power, thermal control, habitable atmosphere, and other common ISS services and capabilities. Due to current power limitations on the ISS, upgrades such as additional solar arrays may be required to support this effort if the requested in-kind support exceeds what is available on the ISS.

The selected company/companies would be able to utilize its module or platform for commercial for-profit activities that are beyond NASA's and the National Lab's missions. As a companion activity to this program, NASA will develop a policy that ensures that NASA or ISS National Laboratory activities do not compete with the capabilities provided by commercial LEO platforms. In the longer term, activities currently supported by NASA and the ISS National Laboratory could be fully transitioned onto these new platforms once available. This will allow private industry to experiment with commercial activities and demonstrate the viability of commercial human spaceflight activities.

Commercial LEO Development will advance the Nation's goals in LEO and exploration by furthering development and maturity of the commercial space market to enable private industry to assume roles that have been traditionally Government-only, and to potentially realize cost savings to the Government by leveraging private industry innovation and commercial market incentives.

EXPLANATION OF MAJOR CHANGES IN FY 2019

N/A

SCIENCE

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	FY 2020	Notional FY 2021	FY 2022	FY 2023
Earth Science	1907.7	--	**1784.2**	1784.2	1784.2	1784.2	1784.2
Planetary Science	1827.5	--	**2234.7**	2199.6	2180.8	2162.1	2143.3
Astrophysics	1352.3	--	**1185.4**	1185.4	1185.4	1185.4	1185.4
Heliophysics	674.7	--	**690.7**	690.7	690.7	690.7	690.7
Total Budget	**5762.2**	**5725.8**	**5895.0**	**5859.9**	**5841.1**	**5822.4**	**5803.6**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

SCIENCE

Astrophysics

SCIENCE

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Earth Science	1907.7	--	**1784.2**	1784.2	1784.2	1784.2	1784.2
Planetary Science	1827.5	--	**2234.7**	2199.6	2180.8	2162.1	2143.3
Astrophysics	1352.3	--	**1185.4**	1185.4	1185.4	1185.4	1185.4
Heliophysics	674.7	--	**690.7**	690.7	690.7	690.7	690.7
Total Budget	**5762.2**	**5725.8**	**5895.0**	**5859.9**	**5841.1**	**5822.4**	**5803.6**
Change from FY 2018			**169.2**				
Percentage change from FY 2018			**3.0%**				

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

From the vantage point of space, NASA captures breath-taking images of our world and the universe. These images advance our scientific understanding in a multitude of disciplines. They also have the power to influence action and inspire learning.

Since NASA’s inception, scientific discovery about our Earth, the Sun, the solar system and the universe beyond has been an enduring purpose of the Agency as part of its three major strategic thrusts: discover, explore, and develop. NASA’s Science Mission Directorate (SMD) conducts scientific exploration enabled by observatories that view Earth from space, observe and visit other bodies in the solar system, and gaze out into the galaxy and beyond. NASA’s science programs focuses on three interdisciplinary objectives:

- Discovering the secrets of the Universe
- Searching for life in the Solar System and beyond
- Safeguarding and improving life on Earth

NASA science programs address fundamental research about the universe and our place in it. They address questions like: How did the universe begin and evolve? How did our solar system originate over time? How and why is the Earth changing on all time-scales? This fundamental research covers all areas of science and the intersections thereof when addressing the question “Are we alone?”. NASA’s science programs also help protect and improve life on Earth through fundamental research that enables innovative and practical applications for decision-makers, including disaster response, natural resource management, and planetary defense. NASA also focuses on improving its operations and is increasingly launching its science missions on schedule and on budget. Our discoveries continue to rewrite textbooks; inspire children to pursue careers in science, technology, engineering, and mathematics (STEM); and demonstrate U.S. leadership worldwide.

SCIENCE

NASA uses the recommendations of the National Academies' decadal surveys as an important input in planning and prioritizing the future of its science programs. For over 40 years, decadal surveys have proven vital in establishing a broad consensus within the national science community on the state of science, the highest priority science questions we can address, and actions we can take to answer those questions. NASA uses these recommendations to prioritize future flight missions, including space observatories and probes, as well as technology development and proposals for theoretical and suborbital supporting research. In determining the content of the Science portfolio, NASA also considers national priorities and policies, actual budgets, existing technological capabilities, partnership opportunities, and other programmatic factors.

EXPLANATION OF MAJOR CHANGES IN FY 2019

This budget continues to reinvigorate robotic exploration of the solar system by providing $2.2 billion for Planetary Science. It includes a new Lunar Discovery and Exploration program that supports public-private partnerships and innovative approaches to achieving human and science exploration goals, including the eventual return of humans to the moon. This new program will enable the establishment of commercial contracts for transportation services, the development of small rovers to be delivered via commercial landers, and the building and launching of instruments that serve lunar science and exploration needs. This budget also establishes a new Planetary Defense program for near-Earth object detection and mitigation, and includes study of a Mars Sample Return mission incorporating commercial and international partnerships.

The budget provides $1.8 billion for a focused, balanced Earth science portfolio that supports the priorities of the science and applications communities. Consistent with the FY 2018 request, the budget assumes termination of four Earth Science missions — Pre-Aerosol, Clouds, and ocean Ecosystem (PACE), Orbiting Carbon Observatory (OCO)-3, Deep Space Climate Observatory (DSCOVR) Earth-viewing instruments, and Climate Absolute Radiance and Refractivity Observatory (CLARREO) Pathfinder — and the Carbon Monitoring System. Following a detailed internal review, NASA has canceled the Radiation Budget Instrument (RBI) due to cost overruns that cannot be accommodated within the current budget.

The budget continues to support the DRIVE initiative, the highest priority recommendation in the Heliophysics decadal survey, and enables space weather-related interagency efforts, with a focus on strengthening the feedback between space weather research and operational forecasting needs.

Given its significant cost and higher priorities within NASA, the budget proposes termination of the WFIRST mission. Remaining WFIRST funding is redirected towards other priorities of the astrophysics community, including competed astrophysics missions and research.

SCIENCE

ACHIEVEMENTS IN FY 2017

SCIENCE RESULTS

NASA investments continue to generate productive science and interesting results. In Planetary Science, Juno--currently in a 53-day orbit--has successfully completed nine science flybys of Jupiter. Juno's instruments have started their mapping of Jupiter's previously unknown interior structure. Initial results indicate that limited rocky material is spread out in a diffuse, "fuzzy" deep core and that the magnetic field may have multiple origins, anchored at various depths within the planet. Deep atmospheric mapping indicates that there is a wide current of ammonia flowing up from the deeps at the equator, hinting at deep circulation patterns. The deep atmosphere below the iconic Great Red Spot is clearly warmer than the surroundings for as far down as we can see, thus hinting at the origins of the Earth-sized superstorm. Particles creating the blazing auroral lights are being mapped back to volcanoes on Jupiter's moon Io but the mysterious, beautiful patterns in the auroral images (in the ultraviolet and infrared) are still being deciphered.

In Astrophysics, for the first time, NASA scientists have detected light tied to a gravitational-wave event, caused by two merging neutron stars in the galaxy NGC 4993, located about 130 million light-years from Earth. On August 17, 2017, NASA's Fermi Gamma-ray Space Telescope picked up a pulse of high-energy light from a powerful explosion and Fermi immediately communicated the status of the explosion to astronomers around the globe as a short gamma-ray burst. Just 1.7 seconds prior to Fermi's detection, the National Science Foundation's twin Laser Interferometer Gravitational-wave Observatory (LIGO) detectors caught a gravitational wave signal from the pair of smashing neutron stars that caused the gamma-ray burst. By combining information from Fermi, LIGO, and a worldwide network of telescopes observing in other wavelengths of light, scientists identified the source as a collision between two neutron stars – ultra-dense, crushed leftover cores of huge stars that exploded as supernovae long ago. In their final moments, this neutron star pair whipped around at nearly the speed of light, ripping at each other and churning out torrents of gravitational energy until they smashed together with a blast of gamma rays that lasted only two seconds. Subsequent observations of this collision revealed the generation of new chemical elements, confirming theoretical predictions made decades ago for such events.

In Earth Science, researchers studied the total column atmospheric carbon dioxide measurements from the OCO-2 instrument using observations over the eastern equatorial Pacific. Results show a significant reduction of carbon dioxide due to reduced outgassing from the ocean at the onset of the 2015-2016 El Niño event, followed by an increase in CO2 due to enhanced respiration and biomass burning in South America. The research also revealed worldwide locations of CO2 emissions with both industrial and natural origins.

In Heliophysics, analysis of data from NASA Heliophysics Voyager, IBEX and Cassini missions suggests a new theory on the shape of the heliosphere. The data indicate that the heliosphere is more spherical rather than comet-shaped as previously thought, without a distinct tail. This is based on a new analysis spanning a full 11-year solar cycle and has yet to be explained comprehensively by theorists, but there is a promising suggestion, based on data from Voyager 1, which is in interstellar space beyond the reach of the solar wind. These data show that the interstellar magnetic field beyond the heliosphere is stronger than scientists previously thought, and possibly leading to plasma interactions that could "compact" the tail. Understanding the shape of the heliosphere gives us crucial information about the space that surrounds us, known as the local interstellar medium, and interactions of stellar spheres elsewhere in the universe.

NASA highlights these and many other scientific results in the pages that follow.

COST AND SCHEDULE PERFORMANCE

The majority of Science missions continue to demonstrate good cost and schedule performance. Since 2011, when NASA implemented a requirement for missions entering development to budget at the 70 percent confidence level, we have launched fourteen Science missions, with a total net budget underrun of six percent.

Nine Science missions under development remain within their original cost estimates: Ionospheric Connection Explorer (ICON), Gravity Recovery and Climate Experiment Follow-On (GRACE-FO), Transiting Exoplanet Survey Satellite (TESS), Parker Solar Probe (PSP), Solar Orbiter Collaboration (SOC), Tropospheric Emissions Monitoring of Pollution (TEMPO), Surface Winds and Ocean Topography (SWOT), the NASA-ISRO Synthetic Aperture Radar (NISAR) mission, and Sentinel-6. In addition, the SMD portion of the Mars 2020 mission remains within its cost commitment, while the HEOMD and STMD contributions have grown slightly.

Costs for NASA's contribution to the European Space Agency (ESA)'s Euclid mission have grown in the past year. Three other Science missions experienced past cost growth above their commitments, but have not grown in the past year: the Interior Exploration using Seismic Investigations Geodesy and Heat Transport (InSight) mission to Mars, the James Webb Space Telescope (Webb) and the Ice, Cloud, and land Elevation Satellite (ICESat)-2.

In January 2018 the Science Mission Directorate conducted a detailed review of the RBI project and canceled the project immediately due to cost growth and technical challenges.

WORK IN PROGRESS IN FY 2018

NASA is operating about 60 Science missions with about 80 spacecraft, most of which involve collaboration with international partners or other U.S. agencies. Work on over 40 missions in formulation and development continues; NASA plans to launch ICON, GRACE-FO, InSight, TESS, and the Parker Solar Probe by the end of FY 2018. Suborbital flights using aircraft, sounding rockets, and balloons are ongoing, as are more than 3,000 competitively selected research awards to scientists located at universities, NASA field Centers, industry, and other government agencies.

The SMD-wide CubeSat/SmallSat initiative is responsive to recommendations from a 2016 National Academies report that concluded that small satellites are suitable to address specific high-priority science goals. An approximate $70 million per year investment supports technology development in all science themes, and provides new partnership opportunities between commercial partners and NASA. During FY 2018 Earth Science will launch the HARP, TEMPEST-D, RainCube, and CubeRRT CubeSats on a single ISS resupply mission.

Later this fiscal year NASA will release Announcements of Opportunity (AOs) for a Heliophysics Explorer mission and Mission of Opportunity, SOFIA Next Generation Instrumentation, and for Earth Venture Instruments-5 (EVI-5), NASA will also release competitive solicitations to develop lunar surface payloads compatible with the expected commercial lunar surface cargo transportation services; robotic payload proposals will be selected that advance NASA's exploration, scientific, and technology development goals.

SCIENCE

KEY ACHIEVEMENTS PLANNED FOR FY 2019

NASA plans to launch the ICESat-2 mission by October 2018. As announced in September 2017, the James Webb Space Telescope (Webb) will complete its assembly and testing, and NASA will ship Webb to the launch site in French Guiana for launch between March and June of 2019.

NASA will select the next New Frontiers mission, Heliophysics Small Explorer and Mission of Opportunity missions, Astrophysics Medium Explorer and Mission of Opportunity missions, and a suite of Earth Venture Suborbital-3 investigations from the AOs released in 2016 and 2017. NASA plans to release AOs for the next Discovery mission, the next Astrophysics Small Explorer and Mission of Opportunity missions, instrument(s) for Missions of Opportunity to the moon, Earth Venture Mission (EVM)-3, and Earth Venture Instrument (EVI)-6.

The CubeSat/SmallSat Initiative will achieve numerous milestones. The Earth Science Technology program plans to launch the Compact Infrared Radiometer in Space (CIRiS) and Compact Spectral Irradiance Monitor-Flight Demonstration (CSIM-FD) CubeSats in FY 2019. NASA will make awards for purchasing and evaluating pilot Earth Science data products from private-sector small satellite constellations. Heliophysics plans to launch the Electron Losses and Fields Investigation (ELFIN) and the CubeSat mission to Understand Solar Particles (CUSP). Planetary Science will select a new SmallSat for development. Astrophysics will start development of two new CubeSats, named BurstCube and SPARCS, continue science operations for HaloSat (scheduled for launch in May 2018), and continue development of CUTE.

Themes

EARTH SCIENCE

From the vantage point of space, NASA satellites can view and study our home planet and its dynamic system of diverse components: the oceans, atmosphere, continents, ice sheets, and life. The Nation's scientific community can thereby observe and track global-scale changes, connecting causes to effects. Scientists can study regional changes in their global context, as well as observe the role that human civilization plays as a force of change. NASA's Earth science activities are an essential part of national and international efforts to understand change at all time-scales and use Earth observations and scientific understanding in service to society. Through its partnerships with other agencies that maintain forecasting and decision support systems, NASA improves national capabilities to predict climate, weather, and natural hazards; manages resources; and inform the development of environmental policy.

The primary recommendations of the National Academies' 2007 Decadal Survey for Earth Science and Applications from Space (ESAS), which informed the 2010 Climate-Centric Architecture plan, were:

- Complete the ongoing program. All legacy Earth Science missions identified in the 2007 ESAS Decadal [Jason-2 (2008), OCO (2009, 2014), Glory (2011), Aquarius (2011), Suomi-NPP (2011), Landsat 8 (2013)] have been developed and launched. OCO-1 and Glory suffered launch vehicle failures. OCO-2 was then developed and successfully launched. The FY 2019 request fully funds operations and science exploitation of these on-orbit missions.
- Continue the balance between flight and non-flight activities. The FY 2019 request fully supports this recommendation.

- Increase the scope and fraction of the Earth Science Technology program. The FY 2019 request fully supports this recommendation, in part through funding for the In-Space Validation of Earth Science Technologies (InVEST), which is part of the SMD-wide CubeSat/SmallSat initiative, leveraging technological progress across the science disciplines.
- Establish a robust program of competed Venture-class missions. The FY 2019 request fully supports this recommendation. It funds all EV missions selected under previous solicitations. It also fully funds the planned future solicitations in all three strands on schedule (4-year cadence for EV-Suborbital and EV-Mission, 18-month cadence for EV-Instrument).
- Aggressively develop a number of future strategic missions. The 2007 ESAS Decadal identified four systematic Tier-1 missions [Soil Moisture Active Passive, ICESat-2, Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI), CLARREO] for launch by 2013. The Decadal also identified five Tier-2 missions [Hyperspectral Infrared Image (HyspIRI), Surface Water Ocean Topography (SWOT), GEOstationary Coastal and Air Pollution Events (GEO-CAPE), Active Sensing of CO2 Emissions over Nights, Days, and Seasons (ASCENDS), and Aerosol-Cloud-Ecosystem (ACE)] by 2016. Those Decadal recommendations assumed unrealistically low mission costs and overly optimistic budgets, rendering the target launch dates unachievable. NASA launched the Soil Moisture Active Passive mission in January 2015, and the Decadal-identified continuity SAGE-III mission in February 2017. The FY 2019 Budget request fully funds ICESat-2 (2018), and the radar portion of DESDynI (NISAR, 2022). The request also funds completion of high-priority, Decadal-identified, continuity missions: Landsat-9 (2021), GRACE-FO (2018, deferred to Tier-3 in the Decadal), and SWOT (2022). These dates are consistent with the latest Key Decision Point decisions and Agency commitments. The budget assumes termination of the PACE mission (previously planned for 2022) and the CLARREO Pathfinder (previously planned for launch to the ISS in 2019).

In January 2018, the National Academies released the second Decadal Survey for Earth Science, which endorsed the current program of record but did not rank the missions in the existing program. This Budget also supports the current program of record, except (as noted above) PACE, OCO-3, RBI, DSCOVR, CLARREO Pathfinder, and the Carbon Monitoring System. NASA will consider Decadal recommendations regarding potential future activities during the FY 2020 and subsequent budget cycles.

NASA asks the Earth Science Advisory Committee for input to ensure that our proposed programs maximize scientific productivity, within the general framework established by the National Academies.

PLANETARY SCIENCE

To answer questions about the solar system and the origins of life, NASA sends robotic space probes to the Moon, other planets and their moons, asteroids and comets, and the icy bodies beyond Neptune. NASA is creating a new Lunar Discovery and Exploration program that is part of the Agency's new exploration initiative. The program will develop instruments and other payloads for missions to the lunar surface. In partnership with industry and with other NASA organizations, the new program will address exploration, science, and technology demonstration objectives as the agency prepares for a sustained program of lunar exploration. NASA also is planning the next Mars rover, which will launch in 2020 and address key questions about the potential for life on Mars. The agency is also heading toward the first fly-by of a Kuiper Belt Object, operating spacecraft at Jupiter, the largest asteroid Ceres, and the Moon, and has begun the journey to a potentially hazardous asteroid, Bennu, to capture and return a sample to Earth.

The primary recommendations of the National Academies' 2012 Decadal Survey for Planetary Science were:

- Continue Discovery solicitations, with the cost cap adjusted for inflation and a 24-month cadence. In the upcoming AO NASA will impose a cost cap of $490M FY2019 constant dollars for phases A through D, not including the cost of the launch vehicle or the value of any non-NASA contributions, per the Decadal recommendation. This cost cap is equivalent to the $450M FY2015 in the previous AO. The out-year budget supports an approximate 30-month cadence for future launches. In addition, the newly created Lunar Discovery and Exploration program will encompass the Lunar Reconnaissance Orbiter and Lunar Future missions' projects.
- Continue New Frontiers with a $1 billion cost cap, and select two new missions by 2022. This budget supports the recommended cost cap for the AO released in February 2017, which will result in the selection of one new mission.
- Begin the two highest priority flagships: a Mars Astrobiology Explorer-Cacher and a Europa mission. This budget supports both the Mars 2020 rover mission that will address the highest priority Mars science objectives recommended by the Planetary Decadal Survey and continued formulation of the Europa Clipper project with a launch readiness date of 2025. The budget includes $50 million in FY 2019 for studies and technology development towards a potential Mars sample return mission.
- Continue missions in development and flight, subject to senior review. This budget supports all missions selected for development, all missions in prime operations, and all extended missions ranked highly in the latest senior review.
- Increase research and analysis (R&A) spending by 5 percent above the FY 2011 budget level, and then 1.5 percent above inflation thereafter. The total R&A budget in FY 2011 was $208 million. This budget funds R&A programs at $247 million in FY 2019.
- Increase Planetary Technology spending to six to eight percent of the total division budget, including completion of the advanced Stirling radioisotope generators. This budget funds technology at roughly 12 percent, including approximately $20 million for Planetary Science's contribution to the SMD CubeSat/SmallSat initiative. Planetary Science has also established a new solar system robotic exploration technology initiative which will accelerate technological innovations that will change the paradigm for robotic solar system exploration
- Achieve a balanced program through a mix of Discovery, New Frontiers, and flagship missions and an appropriate balance among the many potential targets in the solar system. This budget achieves a balanced program by supporting the competed, PI-led programs and two flagship missions (Mars 2020 rover and Europa Clipper). To preserve the balance of NASA's science portfolio and maintain flexibility to conduct missions that were determined to be more important by the science community, the Budget provides no funding for a multi-billion-dollar mission to land on Europa.

NASA asks the Planetary Science Advisory Committee for input to ensure that our proposed programs maximize scientific productivity, within the general framework established by the National Academies.

ASTROPHYSICS

Space is the proving ground for many theories with breathtaking implications for our understanding of the physical universe related to the origin of the universe, black holes, dark matter and dark energy, and planets throughout the universe where life might exist. Having measured the age of the universe, the scientific community now seeks to explore further extremes: its birth, the edges of space and time near black holes, gravitational waves, and the mysterious dark energy filling the entire universe. Scientists have recently developed astronomical instrumentation and analysis methodologies sensitive enough to detect planets around other stars. With thousands of extrasolar planets now known, scientists are using current NASA missions in conjunction with ground-based telescopes to seek Earth-like planets in other solar systems.

The 2010 Decadal Survey in Astronomy and Astrophysics, New Worlds, New Horizons (Astro2010) recommended a coordinated program of research, technology development, ground-based facilities, and space-based missions for implementation during 2012–2021. The primary recommendations were:

- Complete the ongoing program. The Astro2010 Decadal Survey assumed launch of Webb in 2014; full operations of the Stratospheric Observatory for Infrared Astronomy (SOFIA) airborne observatory in 2012; and completion of three Explorer missions: the Nuclear Spectroscopic Telescope Array (NuSTAR) in 2012, the Gravity and Extreme Magnetism (GEMS) Explorer in 2014, and the U.S. contribution to the Japanese ASTRO-H mission in 2014. This budget fully supports launch of Webb in 2019, continued operations of SOFIA through the end of its prime mission in FY 2019, and NuSTAR (launched in 2012). NASA halted development of GEMS in 2012 due to cost overruns. NASA delivered the ASTRO-H instrument to Japan for launch in 2016; in response to the spacecraft failure, this budget supports NASA participation in XARM, Japan's planned recovery mission.
- Support the ongoing core research program to ensure a balanced program that optimizes overall scientific return. This budget fully supports the ongoing core research program and funds a balanced program of strategic and PI-led missions, research and analysis, suborbital projects, and technology development addressing the highest priorities in cosmic origins, exoplanet exploration, and physics of the cosmos.
- Launch WFIRST by 2020. This budget proposes termination of the WFIRST mission in FY 2019 due to its significant cost and higher priorities within NASA. Existing WFIRST funding is redirected towards competed Astrophysics missions and research, high priorities in the Decadal Survey.
- Augment the Astrophysics Explorers Program to support the selection of four missions and four smaller missions of opportunity each decade. This budget, using funding redirected from the WFIRST cancellation, fully supports the recommended cadence of new Astrophysics Explorers missions, with AOs in 2011, 2014, 2016, and 2019, as well as potential start of a new Probe-class mission.
- Launch the Laser Interferometer Space Antenna (LISA) by 2025. This budget supports studies leading toward a potential contribution to an ESA-led gravitational wave observatory for launch in 2034.
- Invest in Technology leading toward an international X-ray observatory in the 2020s. This budget supports a U.S. contribution to the ESA-led Athena advanced X-ray observatory for launch in 2028.
- Invest in a New Worlds technology development and precursor science program for a 2020s mission to image habitable rocky planets. This budget supports studies of two potential missions to image and characterize habitable rocky exoplanets as well as the technologies required to realize them.
- Invest in technology development and precursor science for a 2020s mission to probe the epoch of inflation. This budget supports the development of technology and conduct of precursor science required for a potential future mission to probe the epoch of inflation at the immediate beginning of the universe.
- Increase funding for several targeted areas of supporting research and technology. This budget focuses investments on the science opportunities of CubeSats/SmallSats, taking advantage of the

technological progress in the public and private sector toward meeting high-priority science goals. With funding redirected from the WFIRST cancellation, this budget also supports increased funding for research and analysis including recommended investments in advanced technology development, theoretical and computational networks, suborbital programs, laboratory astrophysics, and technology for future ultraviolet/visible space telescopes.

NASA has and is continuing to address many of the Decadal Survey recommendations, though in some cases at a slower pace. Adjustments to the Decadal Survey recommendations are primarily due to overly optimistic Decadal assumptions regarding future budgets and challenges and delays to programs such as Webb and WFIRST. Other factors that could not be anticipated by the Decadal Survey include changing international partnership opportunities, emerging technologies that have changed what can be accomplished, and advances in our scientific understanding of the universe. The 2016 Midterm Assessment of decadal survey progress found that “NASA has maintained a balanced portfolio through the first half of the decade and, with the assumption of successful completion of an ambitious Explorer schedule, will do so during the second half of the decade as well.” In 2019, NASA will receive the recommendations from the Senior Review of operating Astrophysics missions, which could inform the FY 2021 budget request.

NASA asks the Astrophysics Advisory Committee for input to ensure that our proposed programs maximize scientific productivity, within the general framework established by the National Academies.

HELIOPHYSICS

The Sun, a typical small star midway through its life, governs our solar system. The Sun wields its influence through its gravity, radiation, solar wind, and magnetic fields, all of which interact with the Earth and its space environment. These processes are crucial for our understanding of the universe, but also relate directly to our ability to live in space as they produce space weather, which can affect human technological infrastructure and activities. Using a fleet of sensors on various spacecraft in Earth orbit and throughout the heliosphere, NASA seeks to understand the fundamental processes of how and why the Sun varies; how Earth and our solar system respond to the Sun; how the Sun and the solar system interact with the interstellar medium; and how human activities are affected by these processes. The science of heliophysics, including space weather, enables the predictions necessary to safeguard life and society on Earth and the outward journeys of human and robotic explorers.

The primary recommendations of the National Academies’ 2013 Decadal Survey for Heliophysics were:

- <u>Maintain and complete the current program</u>. The Decadal assumed launch of Van Allen Probes by 2012, Interface Region Imaging Spectrograph (IRIS) by 2013, MMS by 2014, Solar Orbiter Collaboration (SOC) by 2017, Parker Solar Probe by 2018, and continued current funding of the Research program. Van Allen, IRIS, and MMS have launched, and Parker Solar Probe is on schedule. NASA will launch the ESA-led SOC mission by FY 2020.
- <u>Implement the DRIVE (Diversify, Realize, Integrate, Venture, Educate) initiative</u>, including the incorporation of smaller spacecraft and an increase in the competed research program from 10 percent to about 15 percent of the budget request. This budget request meets these objectives, and supports the SMD-wide CubeSat/SmallSat initiative.
- <u>Accelerate and expand the Heliophysics Explorer Program, resulting in an increase to the cadence of competed missions to one launch every 2-3 years</u>. This budget supports the launch of ICON and

GOLD in 2018, five years after the previous Explorer launch. The notional out-year budgets, if realized, would enable the next launch around 2022, and approximately every two years thereafter.

• Restructure Solar Terrestrial Probes (STP) as a moderate-scale, principal investigator-led flight program, and implement three mid-scale missions with an eventual recommended 4-year cadence. This budget supports the AO released in 2017 for a launch of an IMAP mission in about 2024. NASA will initiate Science and Technology Definition Team activities in preparation for two subsequent AOs for multi-spacecraft missions. NASA will competitively select these and all future STP strategic missions from principal investigator-led proposals. The program will also directly benefit from current investments in the CubeSat/SmallSat initiative.

• Implement a large Living with a Star (LWS) mission to study Global Dynamic Coupling with a launch in 2024. NASA has initiated a Science and Technology Definition Team to leverage technical advancements and enable cost-effective solutions, in anticipation of a possible AO in 2019.

The decadal survey also made recommendations related to space weather applications, addressed collectively to the relevant government agencies. NASA will continue collaborating with other agencies to improve space weather observation and forecasting capabilities.

NASA asks the Heliophysics Advisory Committee for input to ensure that our proposed programs maximize scientific productivity within the general framework established by the National Academies.

EARTH SCIENCE

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Earth Science Research	462.0	--	**451.4**	457.4	483.8	507.7	537.8
Earth Systematic Missions	929.7	--	**788.1**	729.5	689.1	646.5	595.0
Earth System Science Pathfinder	208.8	--	**235.0**	273.7	268.2	274.3	287.7
Earth Science Multi-Mission Operations	204.9	--	**196.9**	208.7	225.0	231.6	237.1
Earth Science Technology	62.9	--	**59.7**	61.6	64.2	67.8	69.6
Applied Sciences	39.4	--	**53.1**	53.3	53.9	56.3	57.0
Total Budget	**1907.7**	**--**	**1784.2**	**1784.2**	**1784.2**	**1784.2**	**1784.2**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Earth Science

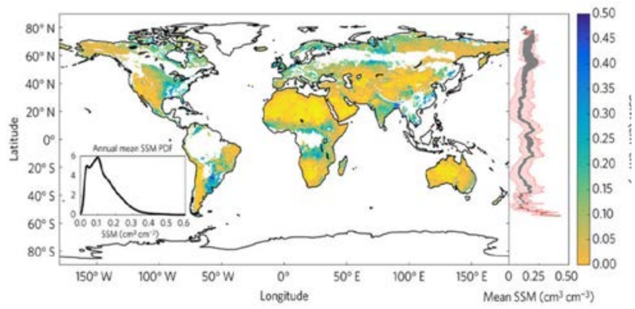
EARTH SCIENCE RESEARCH

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	FY 2020	Notional FY 2021	FY 2022	FY 2023
Earth Science Research and Analysis	332.5	--	**305.2**	299.2	318.0	321.0	325.0
Computing and Management	129.5	--	**146.1**	158.2	165.8	186.7	212.8
Total Budget	**462.0**	**--**	**451.4**	**457.4**	**483.8**	**507.7**	**537.8**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



Global map of annual Surface Soil Moisture, from April 1, 2015 to March 31, 2016, with the probability density function shown in the inset and the zonal mean SSM in the right panel.

NASA's Earth Science Research program develops a scientific understanding of Earth and its response to natural or human-induced changes. Earth is a system, like the human body, comprised of diverse components interacting in complex ways. Understanding Earth's atmosphere, crust, water, ice, and life as a single, connected system is necessary to improve our predictions of climate, weather, and natural hazards. The Earth Science Research program addresses complex, interdisciplinary Earth science problems in pursuit of a comprehensive understanding of the Earth system. This strategy involves six interdisciplinary and interrelated science focus areas, including:

- Water and Energy Cycle: quantifying the key reservoirs and fluxes in the global water cycle, assessing water cycle change, and water quality.
- Weather: enabling improved predictive capability for weather and extreme weather events.
- Earth Surface and Interior: characterizing the dynamics of the Earth's surface and interior and forming the scientific basis for the assessment and mitigation of natural hazards and response to rare and extreme events.
- Climate Variability and Change: understanding the roles of ocean, atmosphere, land, and ice in the climate system and improving our ability to predict future changes.
- Atmospheric Composition: understanding and improving our predictive capability for changes in the ozone layer, Earth's radiation budget, and air quality associated with changes in atmospheric composition.
- Carbon Cycle and Ecosystems: quantifying, understanding, and predicting changes in Earth's ecosystems and biogeochemical cycles, including the global carbon cycle, land cover, and biodiversity.

EARTH SCIENCE RESEARCH

NASA's Earth Science Research program pioneers the use of both space-borne and aircraft measurements in all of these areas. NASA's Earth Science Research program is critical to the advancement of the interagency U.S. Global Change Research Program (USGCRP), established by Presidential Initiative in 1989 and mandated by Congress in the Global Change Research Act of 1990 to develop and coordinate "a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change." NASA's Earth Science Research program also makes extensive contributions to international science programs, such as the World Climate Research Program.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

The Earth Science Advisory Committee determined in October 2017 that NASA remained on track in its annual performance towards the achievement of the research goals relevant to the six science focus areas described in the previous section. FY 2017 research advances made possible by NASA funding include:

A study concluded that high-altitude brown carbon from biomass burning is an under-appreciated component of climate forcing, which is the difference between sunlight absorbed by the Earth and energy radiated back to space. Using aircraft observations from the Search for Emissions, Atmospheric Composition, Clouds, and Climate Coupling By Regional Surveys (SEAC4RS) campaign of vertical aerosol distributions over the continental United States, researchers showed that brown carbon is prevalent in the troposphere. The observations showed that deep convection transports brown carbon to these altitudes, and suggested that brown carbon accounts for about 24 percent of the combined black and brown carbon warming effect at the tropopause.

Nature published an article explaining that drylands are warming more than other areas, with an increase of mean surface temperature of almost 3 degrees Celsius. The researchers used MODIS aerosol and cloud observations, as well as other data, as input to climate model simulations to estimate these radiative effects.

A study explored the impacts of closing three coal-fired power plants in southwestern Pennsylvania to investigate regional air quality from January 2011 through December 2014. The researchers used ground stations measuring particulate matter in order to check the performance of a series of models. Using these observations, this study found that the models were correctly predicting the downward trend in aerosol loading (suspensions of solids and/or liquid particles in the air that we breathe) following each power plant shutdown.

A new statistical model suggests that temperature increases will amplify dust activity in parts of the U.S. in the latter half of the 21st century, which may lead to the increased frequency of large dust storms that have far-reaching impacts on public health and infrastructure. This model eliminates some of the uncertainty found in previous dust activity models by using present-day satellite data such as dust optical depth, leafy green coverage over land, and other factors.

EARTH SCIENCE RESEARCH

Ozone is an important air pollutant at the Earth's surface, and the third most important anthropogenic greenhouse gas in the troposphere. Since 1980, anthropogenic emissions of ozone precursors have shifted from developed to developing regions. NASA's Goddard Earth Observing System Model, Version 5 estimated the increase in ozone burden due to the spatial distribution change. A publication in Nature suggests that increasing emissions in Southeast, East, and South Asia may be most important for the ozone change. The spatial distribution of emissions dominates global tropospheric ozone, suggesting that the mainly emissions from low latitudes will determine future ozone burden

Formaldehyde is a dominant carcinogen in outdoor air and a precursor for tropospheric ozone. A study used satellite data, validated with aircraft in-situ data, and the chemical transport model to map surface air formaldehyde concentrations across the contiguous U.S. Based on this novel dataset, they estimate that up to 12,500 people in the U.S. will develop cancer over their lifetimes by exposure to outdoor formaldehyde. Further, researchers found that formaldehyde levels would decrease by 20-30 percent in the absence of nitrogen oxide emissions resulting from human activities in the U.S. Thus, nitrogen oxide emission controls to improve ozone air quality have a significant co-benefit in reducing formaldehyde-related cancer risks.

An analysis of GPM data shows an improved representation of monsoon precipitation and its interaction with atmospheric dynamics over West Africa. Scientists have developed short-term forecasts of soil moisture and other parameters to understand better the land-atmosphere interactions on scales of days to years. These forecasts are available from the NASA Land Information System based on GPM data along with other precipitation data. Routine Land Information System data assimilation studies performed at NASA Short-term Prediction Research and Transition Center have shown that increased land surface model grid resolution (~3 km) can yield an improvement in the estimation of surface model water balance. GPM's data for extreme precipitation leading to flood or landside events, and the characterization of potential hazards, were a source of several GPM investigations.

Recent published research utilized satellite remote sensing data collected over the past two decades in combination with longer-term fire management records to study changes in areas burned due to human-caused and lightning-ignited fires. While human activities related to the intensification of agriculture have resulted in a decrease in burned area globally over the last 18 years, an increase in human ignitions along with a warming climate are key contributors to increased wildfire area burned in the western U.S. Recent analysis shows that lightning drives interannual and long-term ignition and burned area dynamics in western boreal forest region of North America, increasing wildfire activity, warming conditions and extended fire seasons.

A recent publication reviewed Global precipitation variations over the satellite era using the Global Precipitation Climatology Project monthly, globally complete analyses, which integrate satellite and surface gauge information. Global precipitation variations, during the satellite era, have small increases during El Niños and noticeable decreases after major volcanic eruptions. While the research found no overall significant trend in the global precipitation mean, they did find that there is a pattern of increased rainfall over tropical oceans and decreased rainfall over some middle latitude regions. These observed patterns result from a combination of inter-decadal variations and temperature increases during the study period (1979-2014).

Atmospheric rivers are windy bands of concentrated moisture, which are responsible for the transport of most of the water vapor outside the tropics. A study published in Nature Geosciences, found that atmospheric rivers comprise half of the top 2 percent of the most extreme precipitation and wind distribution events across most mid-latitude regions globally. Atmospheric rivers that make landfall are associated with about 40 to 75 percent of extreme wind and precipitation events over 40 percent of the world’s coastlines. Atmospheric rivers are associated with a doubling (or more) of the typical wind speed and precipitation amounts compared to all storm conditions, and associated with a 50 to 100 percent increase in the probability for an extreme event. They found that the majority of extreme wind events catalogued between 1979 and 2013 over Europe with billion $US losses were associated with atmospheric rivers. They concluded that land-falling atmospheric rivers represent a significant hazard around the globe, because of their association with not only extreme precipitation, but also extreme winds.

NASA selected the Convective Process Experiment as part of the competitive ROSES 2016 to help answer questions about convective storm initiation, organization, and growth. After a year of planning and development, the experiment took place in the North Atlantic-Gulf of Mexico-Caribbean Sea region from May 25 - June 25, 2017, onboard NASA's DC-8 aircraft, based out of Fort Lauderdale, Florida. During the experiment, the science team logged 106 flight hours and 16 science missions (91 hours) that covered a wide range of weather conditions from clear and calm wind, isolated convective cloud systems, to Tropical Storm Cindy (2017).

Research in the past year continued to investigate the processes that govern the sea ice seasonal and long-term evolution. The rapid loss of Arctic sea ice continued this past year, reaching its minimum extent for 2016 on September 10, at 4.14 million square kilometers (1.60 million square miles). This ties the 2007 minimum as the second-lowest extent in the passive-microwave (PMW) satellite record, and reinforces the long-term downward trend in Arctic ice extent (-13.3 percent per decade). The ten lowest September sea ice extents in the satellite record have all occurred in the last ten years.

After four years of record or near-record maximum extents, sea ice around Antarctica plummeted to its lowest minimum extent in the satellite record on March 3, 2017, at 2.11 million square kilometers (815,000 square miles). This reflected especially low sea ice extent along the coast of West Antarctica, particularly in the Amundsen and Ross Seas. The previous record-low minimum extent occurred in February 1997.

A recent study found a connection between the frequency of El Nino events and its influence on global mean surface temperatures. They suggest that El Niño–Southern Oscillation events control inter-annual variations in atmospheric healing rate in the tropics, emphasizing the importance of ocean heat uptake for interpreting global temperature curves. Their analysis explains, for example, the continuing warming trend and rapid temperature rise, associated with atmospheric heat release that accompanies ENSO conditions during 2014-2016. Alternatively, weak El Niño–Southern Oscillation activity can lead to slower rates of increase in global surface temperatures, such as those observed in mid-2000s.

The Arctic-Boreal Vulnerability Experiment (ABoVE) is a major NASA field campaign in Alaska and western Canada over the 2015 to 2023 timeframe. ABoVE seeks a better understanding of the vulnerability and resilience of ecosystems and society to environmental changes in this region. Following the selection of the initial science team in 2015, the team has produced the first version of the ABoVE Science Implementation Plan, and field-based investigations began in January 2016 and continued through 2017. In 2016, NASA initiated SnowEx, a multi-year airborne snow remote sensing campaign, which includes significant ground and aerial observations. SnowEx studies how much water is stored in Earth’s terrestrial snow-covered regions. In the fall of 2016, SnowEx observed snow-free conditions in the Grand Mesa and Senator Beck Basin (Colorado) and researchers installed additional in-situ instruments to monitor meteorological and snow conditions throughout the winter. In February 2017,

EARTH SCIENCE RESEARCH

SnowEx used a unique combination of airborne sensors, including lidar, active and passive microwave, an imaging spectrometer, and infrared cameras to determine the sensitivity and accuracy of different remote sensing techniques for measurements of Snow Water Equivalent, which were complemented by ground-based remote sensing devices and in situ observations taken by over one hundred field participants. Their work and subsequent analysis of all the data collected will help researchers better investigate the distribution of Snow Water Equivalent and the snow energy balance in different terrains and forest canopy types and densities. SnowEx will continue field operations in the winter of 2018-2019.

NASA’s Space Geodesy project completed the commissioning of the joint NASA-United States Naval Observatory broadband VLBI Global Observing System station at NASA’s Kōke‘e Park Geophysical Observatory in Hawaii. The station is now operational. In May 2017, a 24-hour test session was successfully performed using the new station along with the broadband stations at Westford in Massachusetts, Goddard Geophysical, and Astronomical Observatory in Maryland, Wettzell in Germany, and Yebes in Spain. This session is a first of its kind with the combined baseline being the first trans-Pacific/Arctic/Atlantic broadband measurements ever.

Space Geodesy completed negotiations and signed an agreement with the Norwegian Mapping Authority on an agreement for the development and implementation of a NASA satellite laser ranging station in Ny-Ålesund, Norway, a unique location within the Arctic Circle that will be particularly valuable in supporting the tracking of NASA’s polar orbiting satellites.

After the successful implementation of supercomputing pilot modules in 2016 and 2017, the High-End Computing Capability (HECC) project plans to build a large concrete pad in 2018 to enable the future expansion of 16 supercomputing modules in 2019 - 2022 and beyond. The Scientific Computing project will continue to add both computing and storage to its operational high-performance environment at NASA Center for Climate Simulations in 2019 and beyond. The next generation Advanced Data Analytics Platform prototyped during FY 2016 is now operational and supports field campaigns. The ABoVE cloud computing environment is an instance of this platform supporting the ABoVE field campaign in 2017 and 2018. Researchers have used the ABoVE cloud for data processing, archiving, and data analytics. Researchers have developed a high-resolution digital elevation model for the ABoVE campaign region using the ABoVE cloud computing environment. In addition, Scientific Computing will begin to explore the use of computing systems specialized in machine executable learning algorithms to solve problems in climate and weather applications. As the model and observational data continue to grow at increasing rates, leveraging the capabilities of machine learning systems for science will be necessary for future research.

Major airborne campaigns conducted in FY 2017 include ABoVe, Operation IceBridge Arctic and Antarctic, and Hyperspectral Infrared Imager Tropics. In addition, all six Earth Venture Suborbital-2 (EVS-2) investigations conducted airborne campaigns with the Coral Reef Airborne Laboratory investigation, completing its final data collection flights in 2017.

WORK IN PROGRESS IN FY 2018

NASA will continue the implementation of the Atmospheric Tomography (ATom) campaign, capturing global chemical heterogeneity. The ATom aircraft mission (2015–2020) has completed the summer and winter data collection flying NASA’s DC-8 from near the North towards the South Pole along the Pacific Ocean and back towards the North Pole along the Atlantic Ocean. A recent study compared six global chemistry–climate models computing air parcel reactivity. The distinctively different model outputs underline the importance of the measurements currently collected by ATom.

The EXport Processes in the Ocean from RemoTe Sensing (EXPORTS) is a science plan for a future NASA field campaign to develop a predictive understanding of the export and fate of the global ocean's primary production and its implications for the Earth's carbon cycle in present and future climates. NASA plans to execute the EXPORTS field campaign, likely in the Atlantic and Pacific Oceans, during the next five to seven years following a 2016/2017 open competition. NASA's satellite ocean-color data record has revolutionized our understanding of global marine systems by providing synoptic and repeated global observations of phytoplankton stocks and rates of primary production.

The Short-term Prediction Research and Transition (SPoRT) Center will continue to serve in its critical role as facilitator for the transition of unique observations and research capabilities to the operational weather community to improve short-term forecasting. In FY 2018 SPoRT plans to continue support of Geostationary Lightning Mapper (GLM) and Advanced Baseline Imager (ABI) transition and engage with new U.S. partners. Furthermore, SPoRT plans assessments with NWS forecasters whereby operational impacts will be determined. As part of these interactions with forecasters, SPoRT will generate additional applications training materials. SPoRT will conclude SMAP data assimilation activities in FY 2018 and investigate impacts on numerical weather prediction and hydrologic models. SMAP data assimilation links with LIS soil moisture analyses to the Weather Research and Forecasting model in a configuration similar to the NOAA NWS High Resolution Rapid Refresh to demonstrate impacts on convective initiation and severe weather.

NASA's Operation IceBridge continues its approach to make measurements of ice sheet and sea ice thickness in both the Arctic and the Antarctic during each year. In FY 2018, the Antarctic campaign, begun in late October 2017, is different from previous ones because for the first time it will involve aircraft departing from two continents - South America and Antarctica, using different aircraft with complementary payloads. NASA's P-3B aircraft operates from Ushuaia, Argentina, while a commercial Basler aircraft will operate Antarctica (Amundsen-Scott South Pole Station and McMurdo Station). The combined approach will allow for extensive coverage of the Antarctic Peninsula, East Antarctica, and the high latitude Antarctic interior.

The concluding phase of the Salinity Processes in the Upper Ocean Regional Study (SPURS-2) field campaign will take place in 2018. Observers designed this campaign to study the salinity in the upper ocean to better diagnose the physics of air-sea interaction in the rain-dominated ocean regions, linking the changes in the global water cycle to Earth's oceans. This study, begun in 2017 in a low salinity region of the Eastern Pacific Ocean, complements the first SPURS campaign (2012-2013), which took place in a high salinity region in the Central North Atlantic Ocean. As part of this year's deployment, scientists make in situ and remote sensing measurements from the Roger Revelle ship, while researchers recover autonomous instruments deployed during last year's initial phase and deploy additional floats and drifters. The Revelle's operation is coordinated with the schooner Lady Amber. The ship-based measurements help provide detailed process knowledge and observations that can be used in the analysis and interpretation of satellite measurements of sea surface salinity.

As part of a broader cooperative effort in Earth science research and applications, NASA and the Indian Space Research Organization (ISRO) are planning another round of flights by the NASA Airborne Visible/Infrared Imaging Spectrometer – Next Generation (AVIRIS – NG) instrument aboard an ISRO aircraft in 2018. As before, this airborne campaign will generate data products relevant to Earth science research and applications activities in a number of topic areas by capturing spectra from terrestrial, freshwater, and marine sites throughout India. The products will provide ISRO with additional baseline spectroscopy data for a wide variety of Indian environments and offer NASA researchers an opportunity to build upon an important new dataset. Both NASA and ISRO will have access to all scientific data coming from the AVIRIS-NG instrument. This campaign marks another step in a multiyear effort between NASA and ISRO to advance imaging spectroscopy of the Earth.

Modernization of NASA's Global Navigation Satellite Systems (GNSS) Network is underway, and will continue in FY 2018 with new deployment of, state-of-the-art, multi-GNSS receivers capable of generating measurements from all major GNSS. This effort also ensures the Network will be capable of supporting the upcoming GPS Block III satellites, co-located space geodetic measurement techniques, and will continue to support precise timing applications. To take advantage of access to multi-GNSS measurements, JPL successfully delivered new, modernized analysis software GipsyX into operations producing GPS precise orbit solutions.

NASA will perform the Clouds, Aerosol, and Monsoon Processes-Philippines Experiment in partnership with Philippine research and operational weather communities. Currently scheduled for the summer of 2018, it will characterize the role of anthropogenic and natural aerosol particles in modulating the frequency and amount of warm and mixed phase precipitation near the Philippines during the Southwest Monsoon.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

NASA will conduct the Fire Impacts on Regional Emissions and Chemistry (FIREChem) mission, a cooperative biomass burning and air quality field study, in the continental United States from late June to mid-September 2019. FIREChem will focus on the links between satellite and ground-based measurements of both fresh and aged biomass burning plumes generated from both wildfires and prescribed burns (e.g., agriculture and forest management). The FIREChem mission will include in situ measurements and remote sensing observations from the NASA DC-8 to sample upwind and downwind of natural and managed fires. NASA will implement FIREChem in coordination with the National Oceanic and Atmospheric Administration (NOAA).

Major airborne campaigns planned include Operation IceBridge Arctic and Antarctic, FIREChem, and the continuation of the remaining EVS-2 investigations.

In FY 2019 and beyond, HECC plans to add supercomputing systems on the one-acre concrete pad to support the modular computing facility expansion. Scientific Computing will continue to increase its high-performance compute and storage capacities to meet emerging NASA science requirements. Expansions to Scientific Computing's primary services in the Advanced Data Analytics Platform and the next generation data analytics systems will continue. Additional investment into machine learning capabilities (hardware, software, algorithms and applications) will continue in FY 2019.

Program Elements

CARBON CYCLE SCIENCE TEAM

Carbon Cycle Science Team funds research on the distribution and cycling of carbon among Earth's active land, ocean, and atmospheric reservoirs.

GLOBAL MODELING AND ASSIMILATION OFFICE

The Global Modeling and Assimilation Office creates global climate and Earth system component models using data from Earth science satellites and aircraft. Investigators can then use these products worldwide to further their research.

AIRBORNE SCIENCE

The Airborne Science project is responsible for providing aircraft systems to further science and advance the use of satellite data. NASA uses these assets worldwide in campaigns to investigate extreme weather events, observe Earth system processes, obtain data for earth science modeling activities, and calibrate instruments flying aboard earth science spacecraft. NASA Airborne Science platforms support mission definition and development activities. For example, these activities include:

- Conducting instrument development flights;
- Gathering ice sheet observations as gap fillers between missions (e.g., Operation IceBridge);
- Serving as technology test beds for Instrument Incubator Program missions;
- Serving as the observation platforms for research campaigns, such as those competitively selected under the suborbital portion of Earth Venture; and
- Calibrating and validating space-based measurements and retrieval algorithms.

OZONE TRENDS SCIENCE

The Ozone Trends Science project produces a consistent, calibrated ozone record used for trend analyses and other studies.

INTERDISCIPLINARY SCIENCE

Interdisciplinary Science includes science investigations, as well as calibration and validation activities, that ensure the utility of space-based measurements. In addition, it supports focused fieldwork (e.g., airborne campaigns) and specific facility instruments upon which fieldwork depends.

EARTH SCIENCE RESEARCH AND ANALYSIS

Earth Science Research and Analysis is the core of the research program and funds the analysis and interpretation of data from NASA's satellites. This project funds the scientific activity needed to establish a rigorous base for the satellites' data and their use in computational models.

EARTH SCIENCE RESEARCH

FELLOWSHIPS AND NEW INVESTIGATORS

The Fellowships and New Investigators project supports graduate and early career research in the areas of Earth system research and applied science.

SPACE GEODESY

The Space Geodesy Project (SGP) encompasses the development, operation, and maintenance of a global network of space geodetic technique instruments, a data transport and collection system, analysis and the public disseminations of data products required to maintain a stable terrestrial reference system. SGP provides the data and analysis essential for fully realizing the measurement potential of the current and coming generation of Earth Observing spacecraft. Geodesy is the science of measuring Earth's shape, gravity, and rotation and how these properties change over time. The SGP manages the operations and development of NASA's Space Geodetic Network that is comprised of the following major space geodetic observing systems: Very Long Baseline Interferometry, Satellite Laser Ranging, and Global Navigation Satellite System. It currently develops the next generation Space Geodetic Stations. The Space Geodesy project began in 2011. It is a Goddard Space Flight Center (GSFC) and Jet Propulsion Laboratory (JPL) partnership, with participation from the Smithsonian Astrophysical Observatory.

EARTH SCIENCE DIRECTED RESEARCH AND TECHNOLOGY

Earth Science Directed Research and Technology funds the civil service staff who work on emerging Earth Science flight projects, instruments, and research.

GLOBAL LEARNING AND OBSERVATIONS TO BENEFIT THE ENVIRONMENT

Global Learning and Observations to Benefit the Environment (GLOBE) is a worldwide hands-on primary and secondary school-based science and education program that promotes collaboration among students, teachers, and scientists to conduct inquiry-based investigations about our environment. NASA works in close partnership with the National Oceanic and Atmospheric Administration (NOAA) and the National Science Foundation (NSF) Earth System Science Projects to study the dynamics of Earth's environment, focused on atmosphere, hydrology, soil, and land cover. Students take measurements, analyze data, and participate in research in collaboration with scientists.

SCIENTIFIC COMPUTING

The Scientific Computing project funds NASA's Earth Science Discover supercomputing system, high-end storage, and network, software engineering, and user interface projects at GSFC, including climate assessment modeling and data analysis. Scientific Computing supports Earth system science modeling activities based on data collected by earth science spacecraft. The system is separate from the High-End Computing Capability program at NASA Ames Research Center, so it can be close to the satellite data archives at GSFC. The proximity to the data and the focus on satellite data assimilation makes the Discover cluster unique in the ability to analyze large volumes of satellite data quickly. The system currently has approximately 90,000 computer processor cores.

HIGH END COMPUTING CAPABILITY (HECC)

HECC focuses on the Endeavour, Merope, Pleiades, and Electra supercomputer systems and the associated network connectivity, data storage, data analysis, visualization, and application software support. It serves the supercomputing needs of all NASA mission directorates and NASA-supported principal investigators at universities. The funding supports the operation, maintenance, upgrade, and expansion of NASA's supercomputing capability. These four supercomputer systems, with approximately 248,000 computer processor cores, support NASA's aeronautics, human exploration, and science missions. For example, the systems are used to model the aerodynamic characteristics of the Space Launch System (SLS) at different attach angles and different air speeds. The systems also analyze the Kepler mission observation data to search for habitable exoplanets.

DIRECTORATE SUPPORT

The Directorate Support project funds the Science Mission Directorate's (SMD) institutional and crosscutting activities including: National Academies studies, proposal peer review processes, printing and graphics, information technology, the NASA Postdoctoral Fellowship program, working group support, independent assessment studies, procurement support for the award and administration of all grants, and other administrative tasks.

Program Schedule

Date	Significant Event
Q2 FY 2017	Research Opportunities in Earth and Space Science (ROSES)-2017 solicitation release
Q1 FY 2018	ROSES-2017 selection within six to nine months of receipt of proposals
Q2 FY 2018	ROSES-2018 solicitation release
Q1 FY 2019	ROSES-2018 selection within six to nine months of receipt of proposals
Q2 FY 2019	ROSES-2019 solicitation release
Q1 FY 2020	ROSES-2019 selection within six to nine months of receipt of proposals
Q2 FY 2020	ROSES-2020 solicitation release
Q1 FY 2021	ROSES-2020 selection within six to nine months of receipt of proposals
Q2 FY 2021	ROSES-2021 solicitation release
Q1 FY 2022	ROSES-2021 selection within six to nine months of receipt of proposals
Q2 FY 2022	ROSES-2022 solicitation release
Q1 FY 2023	ROSES-2022 selection within six to nine months of receipt of proposals

Program Management & Commitments

Program Element	Provider
Carbon Cycle Science Team	Provider: Various and defined in the acquisition strategy Lead Center: Headquarters (HQ) Performing Center(s): HQ, JPL, GSFC Cost Share Partner(s): USGCRP and Subcommittee on Ocean Science and Technology (SOST) agencies
Global Modeling and Assimilation Office	Provider: Various Lead Center: HQ Performing Center(s): GSFC Cost Share Partner(s): N/A
Airborne Science	Provider: Various Lead Center: HQ Performing Center(s): Armstrong Flight Research Center (AFRC), Ames Research Center (ARC), GSFC Wallops Flight Facility (WFF), Johnson Space Center (JSC), Langley Research Center (LaRC) Cost Share Partner(s): N/A
Scientific Computing	Provider: GSFC Lead Center: HQ Performing Center(s): GSFC Cost Share Partner(s): N/A
Ozone Trends Science	Provider: Various and defined in the acquisition strategy Lead Center: HQ Performing Center(s): LaRC, GSFC Cost Share Partner(s): USGCRP and SOST agencies
Interdisciplinary Science	Provider: Various Lead Center: HQ Performing Center(s): HQ, JPL, GSFC, ARC, AFRC, GRC, LaRC, MSFC, JSC Cost Share Partner(s): USGCRP and SOST agencies
Earth Science Research and Analysis	Provider: Various and defined in the acquisition strategy Lead Center: HQ Performing Center(s): All NASA Centers Cost Share Partner(s): USGCRP and SOST agencies
High-End Computing Capability	Provider: ARC Lead Center: HQ Performing Center(s): ARC Cost Share Partner(s): N/A

EARTH SCIENCE RESEARCH

Program Element	Provider
Directorate Support	Provider: HQ Lead Center: HQ Performing Center(s): Cost Share Partner(s); None
Fellowships and New Investigators	Provider: Various Lead Center: HQ Performing Center(s): All NASA Centers Cost Share Partner(s): N/A
Space Geodesy	Provider: Various Lead Center: GSFC Performing Centers: GSFC, JPL Cost Share Partners: None
Global Learning and Observations to Benefit the Environment	Provider: University Corporation for Atmospheric Research Lead Center: HQ Performing Center(s): HQ, GSFC Cost Share Partner(s): N/A

Acquisition Strategy

NASA implements the Earth Science Research program via competitively selected research awards. NASA releases research solicitations each year in the ROSES NASA Research Announcements. All proposals in response to NASA ROSES are peer reviewed and selected based on defined criteria. The program competitively awards funds to investigators from academia, the private sector, NASA Centers, and other government agencies.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Relevance	Earth Science Advisory Committee	2017	To review progress towards Earth Science objectives in the NASA Strategic Plan	All six science focus areas remained on track in their annual performance towards the achievement of research goals	2018; annually

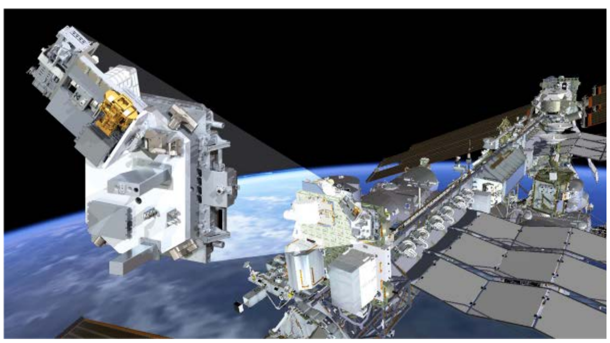
EARTH SYSTEMATIC MISSIONS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Ice, Cloud, and land Elevation Satellite (ICESat-2)	86.5	70.9	**23.1**	17.6	17.6	17.3	17.3
GRACE Follow-On	33.7	4.7	**11.3**	12.3	12.2	12.5	12.5
Surface Water and Ocean Topography Mission (SWOT)	61.7	97.9	**114.3**	85.0	63.9	32.8	11.5
NASA-ISRO Synthetic Aperature Radar (NISAR)	101.4	58.4	**131.9**	118.6	93.2	89.9	32.4
Landsat 9	198.7	175.8	**162.4**	114.9	94.2	10.8	2.9
Sentinel-6	54.7	49.2	**59.6**	64.5	40.4	14.9	35.3
Other Missions and Data Analysis	393.1	--	**285.6**	316.7	367.7	468.4	483.2
Total Budget	**929.7**	--	**788.1**	**729.5**	**689.1**	**646.5**	**595.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



TSIS-1, affixed to the International Space Station in December 2017, will measure the sun's energy input to Earth through the total amount of light that falls on Earth (total solar irradiance) and the distribution of light among different wavelengths (solar spectral irradiance). Satellites have captured a continuous record of the total solar energy input to Earth since 1978, used by scientists to quantify the variations in the Sun's total amount of energy.

Earth Systematic Missions (ESM) includes a broad range of multi-disciplinary science investigations aimed at understanding the Earth system and its response to natural and human-induced forces and changes. Understanding these forces will help determine how to predict future changes and mitigate or adapt to these changes.

The ESM program develops Earth-observing satellite missions, manages the operation of these missions once on orbit, and produces mission data products to support the research and applications communities.

Interagency and international partnerships are a central element throughout the ESM program. Several on-orbit missions provide data products in near-real time for use by U.S. and international meteorological agencies and disaster responders. Five missions involve significant international or interagency collaboration in development. The Landsat Data Continuity Mission (LDCM), now operating on orbit as Landsat 8, involves collaboration with the U.S Geological Survey (USGS). The GPM mission, now operating on orbit, is a partnership with the Japanese Aerospace Exploration Agency (JAXA), and the GRACE Follow-On (GRACE-FO) mission is a partnership between NASA and the German Research Centre for Geosciences (GFZ). The Surface Water and Ocean

Topography (SWOT) mission includes significant collaborations with the Centre National d'Etudes' Spatiales (CNES), the Canadian Space Agency (CSA), and the United Kingdom Space Agency (UKSA). The NISAR mission is a major collaboration between NASA and ISRO. Sentinel-6 is a four-partner collaboration between NASA, the National Oceanic and Atmospheric Administration (NOAA), the European Space Agency (ESA), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). In addition, several on-orbit missions provide data products in near-real time for use by U.S. and international meteorological agencies and disaster responders.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None. Consistent with the FY 2018 Budget Request, this budget provides no funding for the PACE, RBI, CLARREO Pathfinder, and the Earth-viewing instruments on the DSCOVR mission. These missions are being terminated as NASA funding is prioritized towards supporting an innovative and sustainable program of exploration with commercial and international partners.

The RBI would have flown on a future weather satellite to make measurements of the Earth's reflected sunlight and emitted thermal radiation. In January 2018 NASA conducted a detailed review of the RBI project and terminated the project due to cost growth and technical challenges. Similar instruments flying now, including on the recently launched NOAA-20 satellite, will continue to provide continuity for the data record.

Measurements similar to those that would have been taken by the PACE mission are being acquired by other satellites. Under this proposal, NASA will cease funding data processing for the DSCOVR Earth-viewing instruments, which provide images of the sunlit side of the Earth and measure the energy reflected and emitted from it. These instruments do not contribute to the core DSCOVR mission of providing measurements for space weather.

The CLARREO Pathfinder mission would have demonstrated measurement technologies for a larger, more expensive, potential future mission focused on improving detection of climate trends. Other missions funded by NASA are maintaining measurements needed for climate data records. The CLARREO Pathfinder mission is in the earliest stages of implementation and is eliminated to achieve cost savings.

ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023	BTC	Total
Formulation	249.1	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	249.1
Development/Implementation	597.9	86.5	70.9	**9.9**	0.0	0.0	0.0	0.0	0.0	765.1
Operations/Close-out	0.0	0.0	0.0	**13.2**	17.6	13.7	4.5	0.4	0.0	49.3
2018 MPAR LCC Estimate	**847.0**	**86.5**	**70.9**	**23.1**	**17.6**	**13.7**	**4.5**	**0.4**	**0.0**	**1063.6**
Total Budget	**847.0**	**86.5**	**70.9**	**23.1**	**17.6**	**17.6**	**17.3**	**17.3**	**0.0**	**1097.2**
Change from FY 2018				**-47.8**						
Percentage change from FY 2018				**-67.4%**						

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

ICESat-2 will use a multi-beam micropulse laser altimeter to measure the topography of the Greenland and Antarctic ice sheets as well as the thickness of Arctic and Antarctic sea ice. The satellite LIDAR also will measure vegetation canopy heights and support other NASA environmental monitoring missions. By discovering the anatomy of ice loss, researchers may be able to forecast how the ice sheets will melt in the future and what impact this will have on sea-levels.

PROJECT PURPOSE

The ICESat-2 mission will serve as an ICESat follow-on satellite to continue the assessment of polar ice changes. ICESat-2 will measure vegetation canopy heights, allowing estimates of biomass and carbon in above-ground vegetation in conjunction with related missions, and allow measurements of solid earth properties.

ICESat-2 will continue to provide an important record of multi-year elevation data needed to determine ice sheet mass balance and cloud property information. It will also provide topography and vegetation data around the globe in addition to the polar-specific coverage over the Greenland and Antarctic ice sheets.

The ICESat-2 observatory is comprised of one instrument, the Advanced Topographic Laser Altimeter System (ATLAS). The design of ATLAS allows measurement of ice-sheet topography and associated temporal changes, and sea-ice freeboard, which is the difference between the height of the surface of sea ice and surrounding water.

ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

Formulation	Development	Operations

The ICESat-2 mission is a Tier 1 mission in the 2007 National Academies Earth science decadal survey.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

PROJECT PARAMETERS

The ICESat-2 will measure distance by illuminating the Earth's surface with a laser and analyzing the reflected light using a multi-beam photon-counting surface elevation lidar, ATLAS. ICESat-2 will improve the measurements begun with the first ICESat mission by incorporating a micro-pulse multi-beam laser to provide dense cross-track sampling. ICESat-2 will improve elevation estimates over inclined surfaces and very rough (e.g., crevassed) areas and improve lead detection for above-water sea ice estimates. ICESat-2 has a prime mission of three years.

ACHIEVEMENTS IN FY 2017

Following the 2016 ATLAS laser anomaly, the project completed the failure investigation, redesigned, and refurbished the failed laser and spare laser. The project also installed a mass simulator in the ATLAS instrument in place of the removed failed laser, delivered the instrument to the spacecraft manufacturer, and conducted observatory level testing. The project completed the installation of both refurbished lasers as the flight units into the instrument. The project passed its Key Decision Point-D (KDP-D) review and entered into the system assembly, integration and test, launch and checkout phase.

WORK IN PROGRESS IN FY 2018

The project will deliver the ATLAS instrument with refurbished lasers, back to the spacecraft manufacturer for reintegration of ATLAS with the spacecraft and complete observatory-level testing. Scheduled reviews for FY 2018 include the Pre-Ship Review (PSR), Operational Readiness Review (ORR), and KDP-E.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

ICESat-2 plans to launch by October 2018. After the initial in-orbit check-out period, ICESat-2 will commence with mission operations and science data collection.

SCHEDULE COMMITMENTS/KEY MILESTONES

NASA plans to launch ICESat-2 by October 2018 and begin a three-year prime mission. The following timeline shows the development agreement schedule per the rebaseline plan from March 2014, and the current schedule estimates.

ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

Formulation	Development	Operations

Milestone	Confirmation Baseline Date	FY 2019 PB Request
KDP-C	Dec 2012	Dec 2012
Critical Design Review (CDR)	Feb 2014	Feb 2014
New Baseline	Feb 2015	Feb 2015
Systems Integration Review (SIR)	Sep 2016	Aug 2017
KDP-D	Oct 2016	Oct 2017
Operational Readiness Review (ORR)	Jul 2017	Jul 2018
KDP-E	Oct 2017	Aug 2018
Launch	Jun 2018	Oct 2018
End of Prime Mission	Sep 2021	Dec 2021

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2015	763.7	>70	2018	765.1	0.2	Launch	Jun 2018	Oct 2018	+4

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. The estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost. NASA originally baselined ICESat-2 in 2013, it was re-baselined in 2015. The original baseline is provided in the Supporting Data section.

ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**763.7**	**765.1**	**+1.3**
Aircraft/Spacecraft	106.0	123.5	17.5
Payloads	239.1	290.4	51.3
Systems Integration and Test (I&T)	21.6	6.9	-14.7
Launch Vehicle	118.8	137.2	18.4
Ground Systems	55.4	72.0	16.6
Science/Technology	31.0	46.8	15.8
Other Direct Project Costs	191.9	88.3	-103.6

Project Management & Commitments

The Earth Systematic Missions (ESM) Program at GSFC has program management responsibility for ICESat-2. NASA assigned project management responsibility to GSFC.

Element	Description	Provider Details	Change from Baseline
ATLAS Instrument	Advanced Topographic Laser Altimeter System	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Launch Vehicle	Provides launch service and entry into proper Earth orbit	Provider: United Launch Alliance (ULA) Lead Center: GSFC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A

ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Ground System	Provides control of observatory operations, science data processing and distribution	Provider: Orbital ATK Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Spacecraft	Platform provides thermal and attitude control, power, and communications with the instrument	Provider: Orbital ATK Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: Observatory integration and testing reveals any significant issues Then: The NASA will delay launch.	Project currently has 57 days of funded schedule reserves against an internally planning launch date in September 2018. The Agency can support a launch date of October 2018.

Acquisition Strategy

GSFC is responsible for the design and testing of the ATLAS instrument. NASA competitively selected the spacecraft vendor, Orbital ATK. Orbital ATK will provide the ground system element through a contract option. NASA competitively selected United Launch Alliance (ULA) as the launch services vendor.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Ground System	Orbital ATK	Dulles, VA
Spacecraft	Orbital ATK	Gilbert, AZ
Launch Service	ULA	Decatur, AL

ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Feb 2014	CDR	Successful	Aug 2017
Performance	SRB	Aug 2017	SIR	Successful	Jun 2018
Performance	APMC	Oct 2017	KDP-D	Successful	Aug 2018
Performance	SRB	Jun 2018	ORR	TBD	N/A
Performance	APMC	Aug 2018	KDP-E	TBD	N/A

GRACE FOLLOW-ON

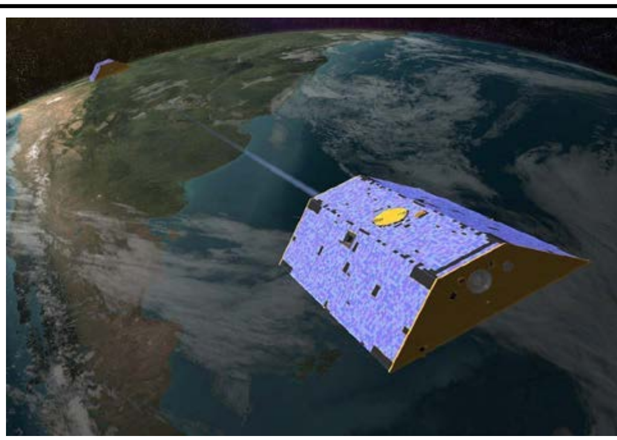
Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023	BTC	Total
Formulation	107.4	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	107.4
Development/Implementation	220.2	22.7	4.7	**0.0**	0.0	0.0	0.0	0.0	0.0	247.6
Operations/Close-out	0.0	11.0	0.0	**11.3**	12.3	12.2	10.2	4.2	0.0	61.2
2018 MPAR LCC Estimate	**327.6**	**33.7**	**4.7**	**11.3**	**12.3**	**12.2**	**10.2**	**4.2**	**0.0**	**416.2**
Total Budget	**327.5**	**33.7**	**4.7**	**11.3**	**12.3**	**12.2**	**12.5**	**12.5**	**0.0**	**426.6**
Change from FY 2018				**6.6**						
Percentage change from FY 2018				**140.4%**						

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



GRACE-FO is a successor to the original GRACE mission, which began orbiting Earth in 2002. The two GRACE-FO satellites will use the same kind of microwave ranging system as GRACE, and so can expect to achieve a similar level of precision. But they will also test an experimental instrument using lasers instead of microwaves, which promises to make the measurement of their separation distance at least 20 times more precise.

PROJECT PURPOSE

The Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) mission will provide continuity of high-resolution global models of Earth’s gravity field, including how it varies over time, as in the original GRACE mission (launched in 2002). The GRACE-FO mission will allow scientists to gain new insights into the dynamic processes in Earth’s interior, currents in the oceans, and variations in the extent of ice coverage. Data from the mission, combined with other existing sources of data, will greatly improve scientific understanding of glaciers and hydrology. GRACE-FO data is vital to ensuring there is a minimal gap in gravitational field measurements following the decommissioning of the original GRACE mission.

GRACE-FO is a partnership with the German Research Centre for Geosciences (GFZ).

GRACE FOLLOW-ON

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

PROJECT PARAMETERS

The GRACE-FO observatory employs two dedicated spacecraft, launched into a near-circular polar orbit. As the two spacecraft orbit Earth, slight variations in gravity will alter the spacecraft speed and distance relative to each other. Scientists use the speed and distance changes to extrapolate and map Earth's gravitational field. The GRACE-FO instrument suite uses the Microwave Instrument to accurately measure changes in the speed and distance between the two spacecraft. The accelerometer instrument measures all non-gravitational accelerations (e.g., atmospheric drag, solar radiation pressure, attitude control, and thruster operation) on each GRACE-FO satellite. The Laser Ranging Interferometer is a technology demonstration and is a partnership between NASA and GFZ. GFZ is responsible for launch. NASA will use the science data from the GRACE-FO mission to generate an updated model of Earth's gravitational field approximately every 30 days for the five-year lifetime of the prime mission.

ACHIEVEMENTS IN FY 2017

GRACE-FO completed final observatory integration and environmental testing of the two spacecraft.

WORK IN PROGRESS IN FY 2018

GRACE-FO completed final alignments and preparations for shipment, and NASA shipped the two GRACE-FO satellites to the Vandenberg Air Force Base launch site in December 2017. The GFZ-planned launch date for GRACE-FO is NLT April 2018. Observatory commissioning will commence for a 90-day period after launch, followed by the start of routine operations.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

The GRACE-FO project, in partnership with GFZ, will continue operations and science data collection from the German Space Operations Center (GSOC) in Oberpfaffenhofen, Germany.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2019 PB Request
KDP-C	Feb 2014	Feb 2014
CDR	Feb 2015	Feb 2015
KDP-D	Aug 2015	Aug 2015
ORR	Jun 2017	Jan 2018

GRACE FOLLOW-ON

Formulation	Development	Operations

Milestone	Confirmation Baseline Date	FY 2019 PB Request
Launch	Feb 2018	Apr 2018
Start Phase E	May 2018	Jul 2018
End of Prime Mission	Feb 2023	Apr 2023

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2015	264	70	2018	247.6	-6%	Launch	Feb 2018	Apr 2018	2

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**264.0**	**247.6**	**-16.4**
Aircraft/Spacecraft	118.7	127.6	8.9
Payloads	32.1	39.5	7.4
Systems I&T	0	0	0
Launch Vehicle	0	0	0
Ground Systems	0	0	0
Science/Technology	12.3	15.5	3.2
Other Direct Project Costs	100.9	65.0	-35.9

GRACE FOLLOW-ON

Formulation	Development	Operations

Project Management & Commitments

GRACE-FO operates under the Earth Systematic Missions (ESM) program at Goddard Space Flight Center (GSFC). NASA assigned project management responsibility to the Jet Propulsion Laboratory (JPL). The GRACE-FO mission is a partnership between NASA and GFZ.

Element	Description	Provider Details	Change from Baseline
Spacecraft	Provides platform for the instruments	Provider: Airbus Defence & Space (Germany) Lead Center: N/A Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Microwave Instrument	Measures the distance between the spacecraft as a function of time	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Accelerometer	Measures all non-gravitational accelerations of the satellite(s)	Provider: French Office National d'Etudes et Recherches Aérospatiales (ONERA) Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Laser Ranging Interferometer	Measures the distance between the two spacecraft as a function of time using a heterodyne interferometric laser (technology demonstration)	Provider: JPL and GFZ Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): GFZ	N/A
Launch Vehicle	Delivers satellites into Earth orbit	Provider: Iridium Communications, SpaceX, Airbus/CASA Espacio Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): GFZ	N/A

GRACE FOLLOW-ON

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The SpaceX Falcon 9 launch manifest is delayed. Then: There would be a delay to the GRACE-FO launch date.	NASA will closely monitor the SpaceX Falcon 9 launch manifest, and will work with our ride share partner, Iridium, to negotiate the most appropriate launch date in the event of a delay.

Acquisition Strategy

The acquisition strategy for GRACE-FO leveraged GRACE heritage by using sole source procurement to the same vendors for major components. NASA completed all major acquisitions.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Spacecraft	Airbus Defence & Space	Germany
Microwave Instrument Ultra Stable Oscillator	Applied Physics Laboratory-Johns Hopkins University	Laurel, MD
Microwave Assemblies	Space Systems/Loral	Palo Alto, CA
Accelerometers	ONERA	Paris, France

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Jul 2012	SRR	Successful	Jan 2014
Performance	SRB	Jan 2014	PDR	Successful	Feb 2015
Performance	SRB	Feb 2015	CDR	Successful	Jul 2015
Performance	SRB	Jul 2015	SIR	Successful	Jan 2018
Performance	SRB	Jan 2018	ORR	TBD	Feb 2018

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023	BTC	Total
Formulation	136.8	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	136.8
Development/Implementation	137.7	61.7	97.9	**114.3**	85.0	59.9	15.0	0.0	0.0	571.5
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	4.0	17.8	11.5	13.5	46.7
2018 MPAR LCC Estimate	**274.4**	**61.7**	**97.9**	**114.3**	**85.0**	**63.9**	**32.8**	**11.5**	**13.5**	**754.9**
Total Budget	**274.4**	**61.7**	**97.9**	**114.3**	**85.0**	**63.9**	**32.8**	**11.5**	**13.5**	**754.9**
Change from FY 2018				**16.4**						
Percentage change from FY 2018				**16.8%**						

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

An artist's conception shows the Surface Water Ocean Topography (SWOT) satellite, which entered the implementation phase in May 2016. SWOT will make high-resolution, wide-swath altimetric measurements of the world's oceans and fresh water bodies to understand their circulation, surface topography, and storage. This multi-disciplinary, cooperative international mission will produce science and data products that will allow for fundamental advances in the understanding of the global water cycle.

PROJECT PURPOSE

The Surface Water Ocean Topography (SWOT) mission will improve our understanding of the world's oceans and terrestrial surface waters. The mission, through broad swath altimetry, will make high-resolution measurements of ocean circulation, its kinetic energy, and its dissipation. These measurements will improve ocean circulation models, leading to better prediction of weather and climate. The mission will also revolutionize knowledge of the surface water inventory on the continents by precise measurement of water levels in millions of lakes and water bodies and the discharge of all major rivers. This will allow for deeper understanding of the natural water cycle and potentially better water management.

The 2007 and 2018 National Academies decadal surveys endorsed SWOT. The mission will complement the Jason oceanography

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

missions, as well as other NASA missions currently in operation and development to measure the global water cycle (Global Precipitation Measurement (GPM), Soil Moisture Active Passive (SMAP), and Gravity Recovery and Climate Experiment Follow-On (GRACE-FO).

SWOT is a collaborative mission with the Centre National d'Études Spatiales (CNES), Canadian Space Agency's (CSA), and United Kingdom Space Agency (UKSA).

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

PROJECT PARAMETERS

SWOT will provide broad-swath sea surface heights and terrestrial water heights for at least 90 percent of the globe using a dual-antenna Ka-band Radar Interferometer (KaRIn). The SWOT payload will also include a precision orbit determination system consisting of Global Positioning System-Payload (GPSP), Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) receivers, and a Laser Retro-reflector Assembly (LRA). In addition, SWOT carries a Nadir Altimeter, and a radiometer for tropospheric path delay corrections. NASA will provide a radiometer designed to determine tropospheric water vapor content, the GPSP system to complement DORIS for precise positioning of the satellite, and a backscattering laser for precise calibration of the other instruments. The CSA will provide a key component of the radar instrument – a set of extended interaction klystrons (EIKs). The CNES will provide radar radio-frequency unit (RFU), the Poseidon-3C Ku-/C-band altimeter, and a DORIS precise orbit determination system. The UKSA will provide commercial applications that will strengthen the international collaborations of the mission. The mission has a prime mission of three years.

ACHIEVEMENTS IN FY 2017

The SWOT project completed the critical design for the GPSP, the KaRIn instrument, conducted the KaRIn Critical Design Review (CDR), and initiated development of the Advanced Microwave Radiometer (AMR) instrument. NASA made the launch vehicle selection for SWOT and awarded a contract to SpaceX for a Falcon 9 “Full Thrust” launch service.

WORK IN PROGRESS IN FY 2018

The SWOT project will complete the Payload System and Project CDRs, initiate build of the KaRIn instrument, complete testing of the AMR instrument, and complete development of the LRA and X-band Telecom subsystem.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2019

The SWOT project will complete the development of the KaRIn and GPSP instruments, initiate development of the integrated payload module, and complete the System Integration Review (SIR).

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2019 PB Request
KDP-C	May 2016	May 2016
CDR	Feb 2018	Feb 2018
KDP-D	Oct 2019	Oct 2019
Launch	Apr 2022	Apr 2022
Start Phase E	Oct 2022	Oct 2022
End of Prime Mission	Oct 2025	Oct 2025

Development Cost and Schedule

NASA and CNES will strive to launch SWOT in April 2021. Consistent with NASA policies regarding commitments to time and schedule, the SWOT launch will occur no later than April 2022.

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2017	571.5	>70	2018	571.5	0	Launch Readiness Date (LRD)	Apr 2022	Apr 2022	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**571.5**	**571.5**	**0**
Aircraft/Spacecraft	0	0	0
Payloads	181.6	231.8	50.2
Systems I&T	4.9	4.9	0
Launch Vehicle	131.3	107.8	-23.5
Ground Systems	34.7	39.7	5.0
Science/Technology	46.7	40.8	-5.9
Other Direct Project Costs	172.3	146.5	-25.8

Project Management & Commitments

The Earth Systematic Missions (ESM) program at Goddard Space Flight Center (GSFC) has program management responsibility for SWOT. NASA assigned project management responsibility to the Jet Propulsion Laboratory (JPL). SWOT is a partnership mission between NASA, CNES, CSA, and UKSA.

Element	Description	Provider Details	Change from Baseline
KaRIn	Makes swath measurements of sea surface topography and lake and river heights	Provider: NASA, CNES, CSA, UKSA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): CNES (RFU), CSA (EIK), UKSA (Duplexer)	N/A
Advanced Microwave Radiometer (AMR)	Provides wet tropospheric delay correction of KaRIn	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
GPSP	Provides orbit determination	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
LRA	Provides orbit determination	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
X-band Telecom	Provides downlink of science data	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Nadir Altimeter	Measures Jason-heritage ocean surface topography at nadir	Provider: CNES Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): CNES	N/A
DORIS	Provides orbit determination	Provider: CNES Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): CNES	N/A
Spacecraft Bus	Provides instrument platform	Provider: CNES Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): CNES	N/A
Launch Vehicle	Delivers spacecraft to orbit	Provider: NASA Lead Center: JPL Performing Center(s): KSC Cost Share Partner(s): N/A	N/A

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The KaRIn RFU delivery from the CNES is not timely, Then: It will delay delivery of the KaRIn instrument.	Project is working closely with CNES to reduce impact on the KaRIn development schedule with the RFU Engineering Model (EM) as an alternate for the Flight Model (FM) during selected testing as well as reordering of KaRIn FM integration & test activities, if necessary.

Acquisition Strategy

The acquisition strategy for SWOT leveraged Jason heritage by using JPL legacy instrument designs (AMR, GPSP, and LRA) and in-house build with a combination of sole source and competitive procurements. The KaRIn leverages Earth Science Technology Office (ESTO) investments and is an in-house development. The X-band Telecom will be a competitive procurement. NASA selected SpaceX to provide a Falcon 9 launch vehicle through a competitive Launch Service Task Order evaluation under the NASA Launch Services II contract.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
X-band Telecom	L3 for modulator, Tesat for traveling wave tube amplifiers	San Diego, CA, Backnang, Germany
Launch Vehicle	SpaceX	Los Angeles, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	May 2014	SRR/Mission Definition Review (MDR)	Successful	Apr 2016
Performance	SRB	Apr 2016	PDR	Successful	Feb 2018
Performance	SRB	Feb 2018	CDR	TBD	Jul 2019
Performance	SRB	Jul 2019	SIR	TBD	Feb 2022
Performance	SRB	Feb 2022	ORR	TBD	N/A

NASA-ISRO SYNTHETIC APERATURE RADAR (NISAR)

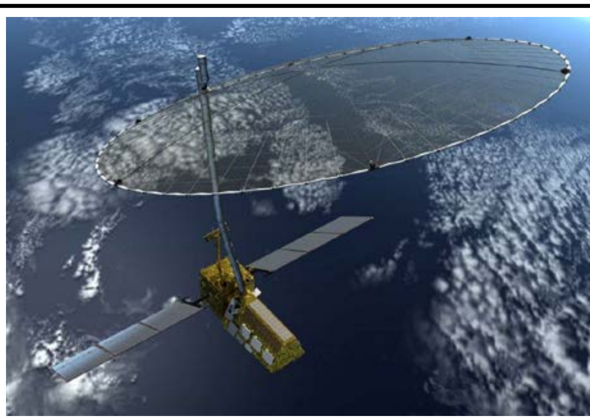
Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023	BTC	Total
Formulation	117.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	117.0
Development/Implementation	110.5	101.4	58.4	**131.9**	118.6	93.2	69.0	0.0	0.0	683.0
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	20.9	32.4	43.6	96.9
2018 MPAR LCC Estimate	**227.5**	**101.4**	**58.4**	**131.9**	**118.6**	**93.2**	**89.9**	**32.4**	**43.6**	**896.9**
Total Budget	**227.5**	**101.4**	**58.4**	**131.9**	**118.6**	**93.2**	**89.9**	**32.4**	**43.6**	**896.9**
Change from FY 2018				**73.5**						
Percentage change from FY 2018				**125.9%**						

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



The NISAR satellite, a joint mission between NASA and the ISRO, will be the first radar imaging satellite to use dual frequencies. NISAR will observe and take measurements of some of the planet's most complex processes, including ecosystem disturbances, ice-sheet collapse, and natural hazards.

PROJECT PURPOSE

The NASA-ISRO Synthetic Aperture Radar (NISAR) mission will provide an unprecedented, detailed view of the Earth using advanced radar imaging and a dual frequency (L- and S-band) Synthetic Aperture Radar (SAR). The mission will observe and measure some of the planet’s most complex processes, including ecosystem disturbances; ice sheet collapse; and natural hazards, such as earthquakes, tsunamis, volcanoes, and landslides. The mission will reveal information about the evolution and state of Earth’s crust, broaden scientific understanding of our planet's changing processes and its effect in changing climate, and aid future resource and hazard management.

Scientists derived the L-band SAR science from the Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI) mission, a 2007 decadal survey Tier 1 mission, recommended by the National Academies. The National Academies 2018 decadal survey also endorses NISAR. NISAR is a collaborative mission with the Indian Space Research Organisation (ISRO).

NASA-ISRO SYNTHETIC APERATURE RADAR (NISAR)

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2019

NASA's request includes funding for additional ground stations, operations of those stations, and associated communication links for NISAR data. This augmentation will generate additional data, including soil moisture and natural hazard data that will be of value to other federal agencies as well as the science community. The data products that will be enabled by this proposal were identified as priority needs by the interagency Satellite Needs Working Group of the U.S. Group on Earth Observations.

PROJECT PARAMETERS

NISAR consists of a dual frequency (L- and S- band) SAR. NASA will provide the L-band SAR, the engineering payload, the payload integration, and payload operations. ISRO will provide the S-band SAR, the spacecraft bus, the launch vehicle, observatory integration and testing, and spacecraft operations. NISAR has a prime mission of three years.

ACHIEVEMENTS IN FY 2017

NISAR completed all planned engineering model (EM) development, testing, and verification. The project completed the build for the L-Band SAR and Flight System, continued detailed design work on the reflector and boom, and completed the reflector Critical Design Review (CDR). The project initiated component and subsystem CDRs.

WORK IN PROGRESS IN FY 2018

NISAR will complete all subsystem and system level CDRs, begin flight hardware builds, and will mature the mission operations concept jointly with ISRO.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

NISAR will complete the Project CDR at JPL and support ISRO's CDR. The project will continue flight model building and subsystem level integration and testing.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2019 PB Request
KDP-C	Aug 2016	Aug 2016
CDR	Oct 2018	Oct 2018
KDP-D	Dec 2019	Dec 2019
Payload delivery to ISRO	Feb 2021	Feb 2021
LRD	Sep 2022	Sep 2022

NASA-ISRO SYNTHETIC APERATURE RADAR (NISAR)

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Curren t Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milesto ne Chang e (mths)
2017	661	>70%	2018	683	3.3%	LRD	Sep 2022	Sep 2022	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**661.0**	**683.0**	**22.0**
Aircraft/Spacecraft	77.1	86.1	9.0
Payloads	211.1	230.6	19.5
Systems I&T	23.0	24.3	1.3
Launch Vehicle	0.6	0.5	-0.1
Ground Systems	72.6	93.8	21.2
Science/Technology	28.2	29.9	1.7
Other Direct Project Costs	248.4	217.8	-30.6

Project Management & Commitments

The Earth Systematic Missions (ESM) program at GSFC has program management responsibility for NISAR. NASA assigned project management responsibility to JPL. NISAR is a partnership between NASA and ISRO.

Element	Description	Provider Details	Change from Baseline

NASA-ISRO SYNTHETIC APERATURE RADAR (NISAR)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
L-band SAR	Radar imaging payload	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
S-band SAR	Radar imaging payload	Provider: ISRO Lead Center: N/A Performing Center(s):N/A Cost Share Partner(s):ISRO	N/A
Spacecraft	Provides platform for the payload	Provider: ISRO Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ISRO	N/A
Launch Vehicle	Delivers observatory to orbit	Provider: ISRO Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ISRO	N/A

NASA-ISRO SYNTHETIC APERATURE RADAR (NISAR)

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The ISRO-provided Geosynchronous Satellite Launch Vehicle Mark II launch vehicle reliability does not meet the NASA-ISRO joint requirements, Then: There may be a significant delay in the launch date.	The project defined and documented five success criteria for the NISAR launch to proceed. On August 27, 2015, and September 8, 2016, ISRO completed successful Geosynchronous Satellite Launch Vehicle launches and met two of the five criteria.
If: The NISAR boom does not deploy in-orbit properly, Then: The project cannot meet the mission success criteria.	The project is addressing the single point failure in the boom electronics. NASA will extensively test the NISAR boom in the flight configuration before delivering it to payload integration and test.

Acquisition Strategy

The design and build of the L-band SAR radar will be an in-house build at JPL, with competed subcontracts.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Solid State Recorder	Airbus	Germany
Reflector Antenna	Astro Aerospace	California

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Dec 2014	SRR/MDR	Successful	Jun 2016
Performance	SRB	Jun 2016	PDR	Successful	Oct 2018
Performance	SRB	Oct 2018	CDR	TBD	Dec 2019
Performance	SRB	Dec 2019	SIR	TBD	Oct 2021
Performance	SRB	Oct 2021	ORR	TBD	N/A

LANDSAT 9

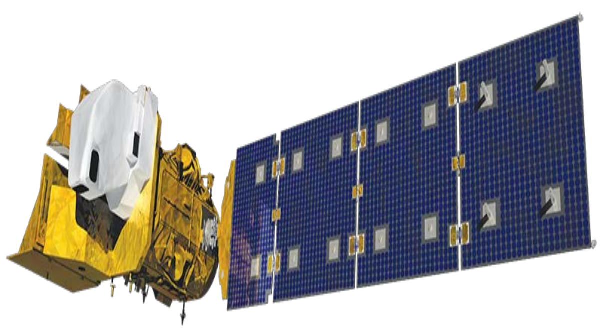
Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023	BTC	Total
Formulation	116.4	118.3	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	234.8
Development/Implementation	0.0	80.3	175.8	**162.4**	114.9	92.9	8.0	0.0	0.0	634.2
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	1.3	2.8	2.9	9.0	16.1
2018 MPAR LCC Estimate	**116.4**	**198.7**	**175.8**	**162.4**	**114.9**	**94.2**	**10.8**	**2.9**	**9.0**	**885.0**
Total Budget	**116.4**	**198.7**	**175.8**	**162.4**	**114.9**	**94.2**	**10.8**	**2.9**	**9.0**	**885.0**
Change from FY 2018				**-13.4**						
Percentage change from FY 2018				**-7.6%**						

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



A rendering of the Landsat 9 spacecraft. Image credit: Orbital ATK

PROJECT PURPOSE

Landsat 9 will extend the record of multi-spectral, moderate resolution Landsat quality data and meet operational and scientific requirements for observing land use and land change.

The Landsat data series, initiated in 1972, is the longest continuous record of changes in Earth’s surface as seen from space and the only U.S. satellite system designed and operated to make repeated observations of the global land surface at moderate resolution. Landsat data is available at no cost, providing a unique resource for people who work in agriculture, geology, forestry, regional planning, education, mapping, and climate research.

The Landsat 9 mission is a collaboration between NASA and the U.S Geological Survey (USGS) and is a cornerstone of our nation’s multi-satellite, multi-decadal, Sustainable Land Imaging (SLI) program. SLI is a NASA-USGS partnership to develop, launch, and operate a spaceborne system and provide researchers and users with high quality, global, continuous land imaging measurements that are

LANDSAT 9

Formulation	Development	Operations

compatible with the existing 45-year Landsat record and will evolve through investment in, and introduction of new sensor and system technologies.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

PROJECT PARAMETERS

Landsat 9 has two science instruments, the Operational Land Imager 2 (OLI-2) and the Thermal Infrared Sensor 2 (TIRS-2), a spacecraft, a mission operations element, and a ground system. Landsat 9 is designed to provide 16-day continuous coverage of the global land mass with spatial resolutions of 15 meters for panchromatic light, 30 meters for visible and near-infrared and shortwave infrared light, and 120 meters for infrared light. In concert with other land-imaging satellites, such as the currently operating Landsat 8 satellite, Landsat 9 will contribute to increased repeat coverage for U.S. users. NASA will build, launch, and perform the initial checkout and commissioning of the satellite. USGS will develop the ground system, operate the Landsat 9 observatory, and process, archive, and freely distribute the mission's data. Landsat 9 has a prime mission of five years.

ACHIEVEMENTS IN FY 2017

Landsat 9 completed the mission-level Preliminary Design Review (PDR). NASA selected the Atlas V launch vehicle for Landsat 9 and awarded a contract to United Launch Services LLC (ULS).

WORK IN PROGRESS IN FY 2018

The Landsat 9 project will pass its Key Decision Point-C (KDP-C) review, enter into the final design and fabrication activities phase, and complete its mission-level Critical Design Review (CDR).

KEY ACHIEVEMENTS PLANNED FOR FY 2019

The Landsat 9 project will complete its System Integration Review (SIR), and prepare for its KDP-D review, and entrance into the system assembly, integration and test, launch and checkout phase.

LANDSAT 9

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2019 PB Request
KDP-C	Dec 2017	Dec 2017
Critical Design Review	Apr 2018	Apr 2018
System Integration Review	Aug 2019	Aug 2019
KDP-D	Dec 2019	Dec 2019
Operational Readiness Review	Sept 2020	Sept 2020
Launch	Nov 2021	Nov 2021
Handover to USGS	Mar 2022	Mar 2022

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Chang e (%)	Key Mileston e	Base Year Mileston e Data	Current Year Mileston e Data	Mileston e Change (mths)
2018	634.2	>70%	2018	634.2	0%	LRD	Nov 2021	Nov 2021	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**634.2**	**634.2**	**0**
Aircraft/Spacecraft	98.1	98.1	0
Payloads	107.6	107.6	0
Systems I&T	0	0	0

LANDSAT 9

Formulation	Development	Operations

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
Launch Vehicle	154.4	154.4	0
Ground Systems	17.2	17.2	0
Science/Technology	9.2	9.2	0
Other Direct Project Costs	247.7	247.7	0

Project Management & Commitments

The Earth Systematic Missions (ESM) program at GSFC has program management responsibility for Landsat 9. NASA assigned project management responsibility to GSFC. The Landsat 9 mission is a partnership between NASA and USGS.

Element	Description	Provider Details	Change from Formulation Agreement
Operational Land Imager 2	Provide moderate resolution, multi-channel, wide swath visible imaging of the Earth's surface, consistent with previous Landsat missions.	Provider: Ball Aerospace Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	
Thermal Infrared Sensor 2	Provide moderate resolution thermal infrared imaging of the Earth’s surface, consistent with previous Landsat missions.	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	
Spacecraft	Provide a platform with performance commensurate with OLI-2 and TIRS-2 requirements.	Provider: Orbital ATK Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	
Launch Vehicle	Provide launch services for the Landsat 9 Observatory.	Provider: United Launch Services LLC Lead Center: GSFC Performing Center: KSC Cost Share Partner(s): N/A	

LANDSAT 9

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Ground System	Collect, process, archive, and freely distribute Landsat data.	Provider: General Dynamics Mission Systems (GDMS) Lead Center: USGS EROS Performing Center(s): USGS EROS Cost Share Partner(s): USGS	
Mission Operations Element	Provide software and system with capabilities for command and control, mission scheduling, long-term trending and flight dynamics analysis.	Provider: General Dynamics Mission Systems (GDMS) Lead Center: USGS EROS Performing Center(s): USGS EROS Cost Share Partner(s): USGS	

Project Risks

Risk Statement	Mitigation
If: Continued functional testing of the TIRS-2 Imaging Performance and Cryoshell Evaluation test program does not result in a successful detector image, Then: There is a possibility of continued troubleshooting of an unknown issue between the Focal Plane Electronics, harness, & detector, resulting in technical impacts, loss of schedule and increased cost.	The TIRS-2 Team is following a rigorous, thorough, and cautious approach to troubleshooting. Key GSFC Subject Matter Experts are assisting with the troubleshooting and diagnostic process.

Acquisition Strategy

The acquisition strategy for Landsat 9 is the same strategy used for Landsat 8, formerly known as Landsat Data Continuity Mission (LDCM). NASA selected Ball Aerospace to provide the OLI-2 instrument through a sole source procurement. NASA selected Orbital ATK to provide the Landsat 9 spacecraft through the GSFC Rapid Spacecraft Development Office selection process. NASA assigned the TIRS-2 instrument as a directed development to GSFC. NASA selected United Launch Services LLC (ULS) to provide an Atlas V launch vehicle through a competitive Launch Service Task Order evaluation under the NASA Launch Services II contract.

LANDSAT 9

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
OLI-2	Ball Aerospace	Boulder, Colorado
TIRS-2	GSFC	Greenbelt, Maryland
Spacecraft	Orbital ATK	Gilbert, Arizona
Launch Vehicle	United Launch Services LLC	Decatur, Alabama

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Jun 2016	SRR	Successful	Sept 2017
Performance	SRB	Sept 2017	PDR	Successful	Apr 2018
Performance	SRB	Apr 2018	CDR	TBD	Aug 2019
Performance	SRB	Aug 2019	SIR	TBD	Sept 2020
Performance	SRB	Sept 2020	ORR	TBD	Nov 2020

SENTINEL-6

Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023	BTC	Total
Formulation	15.5	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	15.5
Development/Implementation	22.8	54.7	49.2	**59.6**	64.5	40.1	9.4	32.0	133.6	465.9
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.3	5.5	3.3	29.4	38.4
2018 MPAR LCC Estimate	**38.2**	**54.7**	**49.2**	**59.6**	**64.5**	**40.4**	**14.9**	**35.3**	**163.0**	**519.8**
Total Budget	**38.2**	**54.7**	**49.2**	**59.6**	**64.5**	**40.4**	**14.9**	**35.3**	**163.0**	**519.8**
Change from FY 2018				**10.4**						
Percentage change from FY 2018				**21.1%**						

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

An artist's conception shows one of the two Sentinel-6 satellites. Sentinel-6's primary mission objective is to continue ocean surface topography measurements beyond TOPEX/Poseidon and the Jason series of satellites, providing measurements essential to climate studies and operational oceanography. As a secondary objective, Sentinel-6 will collect high-resolution vertical profiles of atmospheric temperature, using GNSS radio occultation sounding techniques to support numerical weather prediction. Credit: ESA 2015, Airbus Defence and Space

PROJECT PURPOSE

The Sentinel-6 mission will provide continuity of ocean topography measurements beyond the Topography Experiment (TOPEX)/Poseidon (launched in 1992), Jason-1 (2001), OSTM/Jason-2 (2008), and Jason-3 (2016) missions. The Sentinel-6 mission consists of two satellites, Sentinel-6A and -6B, that will launch approximately five years apart to extend measurement continuity for at least another decade. This mission will serve both the operational user community and the scientific community by enabling the continuation of multi-decadal ocean topography measurements for ocean circulation and climate studies.

As a secondary mission objective, Sentinel-6 will characterize atmospheric temperature and humidity profiles by measuring bending angles of Global Navigation Satellite System (GNSS) signals occulted by the Earth's atmosphere. The project will process these measurement products

SENTINEL-6

Formulation	Development	Operations

on Earth within a few hours of acquisition on board the satellite and make them available for ingestion into National Weather Service models to support weather forecasting capabilities.

Sentinel-6 is a collaborative mission with the National Oceanic and Atmospheric Administration (NOAA), the European Space Agency (ESA), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

PROJECT PARAMETERS

NASA will provide the launch vehicle and launch services for each of the Sentinel-6 spacecraft, two sets of three instruments consisting of the NASA altimetry payload that includes Advanced Microwave Radiometer-Climate Quality (AMR-C), the GNSS-Radio Occultation (GNSS-RO) receiver, and a Laser Reflector Array (LRA). Additionally, NASA will provide services required to perform the NASA payload integration and test, mission operations support for the NASA-developed instruments, and technical support to the United States ground system team, as well as, an operational science data processor for the AMR-C to EUMETSAT to integrate into the overall mission science data processing chain. Moreover, NASA will provide near-real time and offline data processing for GNSS-RO data in addition to mission data product archiving and distribution. Sentinel-6A and 6B observatories have a five-and-a-half year prime mission.

ACHIEVEMENTS IN FY 2017

The Sentinel-6 project completed its Key Decision Point-B (KDP-B), Preliminary Design Review (PDR), KDP-C, and preparation for its Critical Design Review (CDR).

WORK IN PROGRESS IN FY 2018

NASA made the launch vehicle selection for Sentinel-6 and awarded a contract to SpaceX for a Falcon 9 Full Thrust launch service. The Sentinel-6 project will complete its CDR and initiate the build of the NASA payload instruments.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

The Sentinel-6 project will complete the development and testing of the Sentinel-6A NASA instrument payload; ship it to the ESA spacecraft integrator, Airbus; and complete the Systems Integration Review (SIR) and KDP-D.

SENTINEL-6

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2019 PB Request
KDP-C	Apr 2017	Apr 2017
CDR	Oct 2017	Oct 2017
Sentinel-6A US Payload delivery to ESA	Mar 2020	Mar 2020
Sentinel-6B US Payload delivery to ESA	Oct 2020	Oct 2020
Launch (Sentinel-6A)	Nov 2021	Nov 2021
Start Phase E (Sentinel-6A)	Feb 2022	Feb 2022
End Prime Mission (Sentinel-6A)	Aug 2027	Aug 2027
Launch (Sentinel-6B)	Nov 2026	Nov 2026
Start Phase E (Sentinel-6B)	Feb 2027	Feb 2027
End Prime Mission (Sentinel-6B)	Aug 2032	Aug 2032

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2017	465.9	>70%	2018	465.9	0	LRD of Sentinel-6A	Nov 2021	Nov 2021	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

SENTINEL-6

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**465.9**	**465.9**	**0**
Aircraft/Spacecraft	0	0	0
Payloads	65.8	77.6	11.8
Systems I&T	8.8	8.1	-0.7
Launch Vehicle	280.7	275.7	-5.0
Ground Systems	9.7	6.7	-3.0
Science/Technology	4.4	3.6	-0.8
Other Direct Project Costs	96.5	94.2	-2.3

Project Management & Commitments

The Earth Systematic Missions (ESM) program at GSFC has program management responsibility for Sentinel-6. NASA assigned project management responsibility to JPL. Sentinel-6 is a partnership between the NOAA, the ESA, and the EUMETSAT.

Element	Description	Provider Details	Change from Baseline
AMR-C	Provides high spatial resolution wet tropospheric path delay corrections for the ESA-supplied Ku/C-Band Altimeter	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
GNSS-RO	Supports secondary mission objectives for weather modeling and forecasting	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
LRA	Provides orbit determination	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A

SENTINEL-6

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Ku/C-Band Altimeter	Measures Jason-heritage ocean surface topography at nadir	Provider: ESA Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
DORIS	Provides orbit determination	Provider: ESA Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Spacecraft Bus	Provides instrument platform	Provider: ESA Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Launch Vehicle	Delivers spacecraft to orbit	Provider: NASA Lead Center: JPL Performing Center(s): KSC Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: The AMR-C Supplemental Calibration System (SCS) becomes stuck at some location away from the science position due to an operational failure of the mechanism, Then: The baseline AMR-C measurements will be lost.	Project is following processes for eliminating foreign object debris (FOD) in mechanical assemblies, ensuring large torque margins, conducting a robust test program, building an engineering model (EM) and performing a full life test, and using on-orbit torque/drag monitoring to park the SCS in science position and discontinue routine internal calibrations, if required.

Acquisition Strategy

Sentinel-6 leverages Jason heritage by using JPL legacy instrument designs (AMR-C, GNSS-RO, and LRA) and in-house build with a combination of sole source and competitive procurements. NASA selected SpaceX to provide a Falcon 9 launch vehicle through a competitive Launch Service Task Order evaluation under the NASA Launch Services II contract.

SENTINEL-6

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
GNSS-RO Electronics	MOOG	Golden, CO
AMR-C Antenna	ATK	San Diego, CA
LRA	ITE	Laurel, MD
Launch Services	SpaceX	Los Angeles, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Aug 2016	MCR/SRR/MDR	Successful	Feb 2017
Performance	SRB	Feb 2017	PDR	Successful	Oct 2017
Performance	SRB	Oct 2017	CDR	Successful	Jan 2019
Performance	SRB	Jan 2019	Sentinel-6A U.S. Payload Pre-Ship Review (PSR-A)	TBD	Sep 2019
Performance	SRB	Sep 2019	Sentinel-6B U.S. Payload Pre-Ship Review (PSR-B)	TBD	Aug 2021
Performance	SRB	Aug 2021	Sentinel-6A ORR	TBD	Aug 2026
Performance	SRB	Aug 2026	Sentinel-6B ORR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Earth Systematic Missions (ESM) Research	17.6	--	**17.3**	22.1	22.9	23.9	27.0
Ocean Surface Topography Science Team (O	5.7	--	**5.7**	5.8	5.8	5.9	6.0
Earth Observations Systems (EOS) Researc	21.7	--	**13.2**	10.7	10.7	10.7	10.7
Sage III	4.2	--	**5.0**	4.8	4.6	4.6	4.7
Radiation Budget Instrument (RBI)	53.0	--	**0.0**	0.0	0.0	0.0	0.0
Sustainable Land Imaging	5.8	--	**7.4**	34.0	64.9	140.0	170.8
Earth from ISS	2.8	--	**2.6**	2.6	2.1	1.7	1.7
Plankton,Aerosols,Clouds,ocean Ecosystem	52.8	--	**0.0**	0.0	0.0	0.0	0.0
Total Solar Irradiance Sensor-2 (TSIS-2)	3.6	--	**8.3**	10.0	10.0	10.0	10.0
Earth Radiation Budget Science	14.0	--	**13.6**	13.8	14.0	14.3	14.7
Ozone Mapping and Profiler Suite (OMPS)	0.0	--	**7.0**	7.0	6.2	4.5	4.6
Total Solar Irradiance Sensor-1 (TSIS-1)	8.6	--	**4.8**	4.7	4.9	4.7	4.8
CLARREO Pathfinder	6.3	--	**0.0**	0.0	0.0	0.0	0.0
Decadal Survey Missions	13.1	--	**21.3**	25.8	49.5	71.8	49.0
Earth Science Program Management	31.3	--	**36.6**	36.7	38.9	40.8	40.3
Precipitation Science Team	6.9	--	**6.2**	6.3	6.4	6.5	6.6
Ocean Winds Science Team	4.2	--	**3.0**	3.0	3.0	3.1	3.2
Land Cover Science Project Office	1.5	--	**1.3**	1.3	1.3	1.3	1.4
Ocean Salinity Science Team	3.9	--	**7.3**	7.4	7.5	7.6	7.8
Soil Moisture Active and Passive (SMAP)	6.9	--	**10.0**	10.0	10.0	10.0	10.0
Quick Scatterometer	2.8	--	**0.7**	0.0	0.0	0.0	0.0
Tropical Rainfall Measuring Mission	3.2	--	**0.0**	0.0	0.0	0.0	0.0
Deep Space Climate Observatory	2.4	--	**0.0**	0.0	0.0	0.0	0.0
Global Precipitation Measurement (GPM)	19.7	--	**20.4**	20.7	20.9	20.9	21.5
Landsat 8	2.2	--	**0.0**	0.0	0.0	0.0	0.0
Ocean Surface Topography Mission (OSTM)	2.4	--	**2.3**	2.3	0.0	0.0	0.0
Suomi National Polar-Orbiting Partnershi	2.9	--	**3.5**	3.6	3.7	3.8	3.9
Terra	27.9	--	**27.7**	28.2	27.9	28.5	29.2
Aqua	29.6	--	**29.9**	30.6	30.3	31.0	31.8
Aura	29.6	--	**25.2**	20.3	22.4	22.8	23.4
SORCE	4.8	--	**5.5**	4.9	0.0	0.0	0.0
Earth Observing-1	1.6	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**393.1**	**--**	**285.6**	**316.7**	**367.7**	**468.4**	**483.2**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

OTHER MISSIONS AND DATA ANALYSIS

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Earth Systematic Missions Other Missions and Data Analysis includes operating missions and their science teams and competed research projects. Mission science teams define the scientific requirements for their missions and generate algorithms used to process the data into useful data products. The research projects execute competitively selected investigations related to specific mission measurements.

Also included here are missions in formulation; and smaller missions in formulation and development, such as TSIS (Total Solar Irradiance Sensor)-1 and TSIS-2.

Mission Planning and Other Projects

EARTH SYSTEMATIC MISSIONS (ESM) RESEARCH

ESM Research funds various science teams for the Earth Systematic missions. These science teams are composed of competitively selected individual investigators who analyze data from the missions to address related science questions.

Recent Achievements

Urban heat islands have been long studied using both ground-based observations of air temperature and remotely sensed thermal infrared data. Researchers recently developed algorithms to retrieve near-surface air temperatures using microwave radiometer data, enabling characterization of urban heat islands in major metropolitan areas around the globe. A recent study compared surface air temperatures derived from the AMSR-E onboard Aqua and AMSR2 onboard JAXA’s GCOM-W1 satellites with station observations from the Global Historical Climate Network for 27 major cities across North America. Results show that temperature differences between urban areas versus rural areas may vary according to different datasets or locations, day-night differences in temperature are consistently lower in urban areas than in rural areas.

Although the Soil Moisture Active/Passive (SMAP) mission measures and quantifies soil moisture over the continents, a new investigation showed that scientists could also utilize SMAP data to monitor ocean winds. The near-surface ocean wind is a driving force in air-sea interaction process and is a key component in forecasts of tropical cyclone track and intensity, thus requiring accurate direct observations of the surface wind field. However, traditional spaceborne radiometers and scatterometers, operating at C- to Ka-band frequencies, have limited sensitivity to strong, hurricane winds. The study demonstrated the advantage of using L-band microwave wind radiometers from SMAP in filling in a critical gap for surface observations during severe weather. A related study further examined the accuracy of the derived SMAP wind products using radar-only and combined active/passive algorithms. That analysis suggests that SMAP wind vectors performance is superior to traditional scatterometers for high-wind conditions (>12.5 m/s), which has the potential to open new frontiers in marine hazard avoidance.

A recent study combined soil moisture data from SMAP, terrestrial water storage, enhanced vegetation index, and solar-induced fluorescence to investigate multiple aspects of the water cycle, as well as coupling points with the carbon cycle. They found that during nominal years the vegetation-moisture relationship is generally within the range of the average yearly precipitation. However, they found that since the previous drought, vegetation growth enhanced sensitivity to surface soil moisture variations, implying that grassland, though susceptible to drought, is able to make a speedy recovery.

OCEAN SURFACE TOPOGRAPHY SCIENCE TEAM (OSTST)

Ocean Surface Topography Science Team (OSTST) uses scientific data from the Ocean Surface Topography Mission (OSTM) and Jason radar altimetry satellites, together with data from international altimetry satellites such as ESA’s Sentinel-3a, to measure global sea surface height. Sparse data from tide gauges and a handful of calibration stations such as the Harvest oil platform help validate the satellite data. Ocean Surface Topography Mission (OSTM) and Jason satellites to measure global sea surface height.

Recent Achievements

Over the past nine years, OSTM has precisely measured the height of 95 percent of the world's ice-free ocean every 10 days. Since its launch in June 2008, it has measured a 1.6-inch (4-centimeter) increase in global mean sea level, which has been rising at a rate of about 0.12 inches (3 millimeters) a year since satellite altimetry records began in 1993. But as OSTM’s onboard systems age and key components begin to show signs of cumulative space radiation damage, it has become prudent to move the older satellite out of its current shared orbit with Jason-3. The move is designed to safeguard the orbit for Jason-3 and its planned successor, Jason-CS/Sentinel-6, planned for launch in 2020.

In its new orbit, OSTM will also undertake a new science mission. The orbit will allow OSTM to collect data along a series of very closely spaced ground tracks just 5 miles apart. The result will be a new, high-resolution estimate of Earth's average sea surface height. The shape of the sea surface is partly determined by underwater hills and valleys, which pull the water due to the force of gravity. Scientists will use these new OSTM data to improve maps of the shape and depth of the sea floor, resolving many presently unknown seamounts (underwater mountains) and other geologic features on the ocean bottom. These new maps will permit advances in ocean modeling, tsunami wave forecasting, and naval operations support, and will boost understanding of the dynamics of the solid Earth.

The data will also help prepare for the next generation of global satellite altimetry missions, including the NASA/CNES/Canadian Space Agency/UK Space Agency Surface Water and Ocean Topography (SWOT) mission, planned for launch in 2021; and Sentinel-3B, planned for launch by the European Space Agency in early 2018.

EARTH OBSERVATION SYSTEMS (EOS) RESEARCH

EOS Research funds science for the EOS missions, currently Terra, Aqua, Aura, and ICESat missions. The project competitively selects individual investigators to undertake research projects that analyze data from specific missions. Whereas, overall, the selected activities focus on science data analyses, some funded activities continue algorithm improvement and validation for the EOS mission instrument data products.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

A new dataset from Aura's tropospheric emission spectrometer measurements provided insights into spatial and temporal variations of trace gases including ammonia, formic acid, methanol, and ozone over 19 megacities since 2013. The study showed that while Mexico City has severe pollution events, the levels of pollution in Lagos are much higher and more persistent. Based on this study, Science Magazine requested data from all 19 sites and published an article on the frequency of high ozone and ammonia days around the world. The Science article concluded that South Asia, in particular, has a large proportion of both high-ozone and high-ammonia days, indicating a significant health risk for the urban population.

Nature published a case study using Aqua's Moderate Resolution Imaging Spectroradiometer (MODIS) aerosol and cloud data showing that a massive volcanic eruption in Iceland reduced the size of liquid cloud droplets—consistent with expectations—but had no discernible effect on other cloud properties. The reduction in droplet size led to cloud brightening. Changes in cloud amount or cloud liquid water path, however, were undetectable, indicating that aerosol changes do not impact these indirect effects, and cloud systems in general. These results represent an important constraint on climate models.

Multiple sources of satellite observations are extremely useful for large-scale crop monitoring and yield estimation, which is important for both scientific and practical applications. For this purpose, a new study investigated use of MODIS Enhanced Vegetation Index, AMSR-E Vegetation Optical Depth and other related variables. Modeling analysis for a period between 2007 and 2009 revealed that the first modeled component of crop aboveground biomass explained 82 percent of the variability of modelled crop yield, and the second component, dominated by environmental stresses, explained 15 percent of the variability.

A study demonstrated an improved accounting of Snow Water Equivalent (SWE) – a common snowpack measurement - using AMSR-E passive microwave measurements for the sparsely forested Upper Kern watershed in the southern Sierra Nevada. Dry snow season (1 Dec – 28 Feb) observations showed a new technique into model predictions of SWE at 90-meter spatial resolution. Evaluated against snow courses (permanent sites that represents snowpack conditions at a given elevation in a given area) and snow pillows (devices measuring SWE of snow packs), the method showed good agreement. This is a marked improvement with a reduction in bias of 84 percent over the model prediction without using the new technique.

Two strong cyclones passed through the Chukchi Sea in August 2016, likely contributing to the observed acceleration of ice loss in the Arctic just prior to the September minimum. The role of such storms has been the focus of increasing study in recent years. A recent study used data from the Atmospheric Infrared Sounder, onboard the Aqua satellite, to examine the impact of a large Arctic cyclone in December 2015 in the Barents and Kara Seas. They found that the anomalously warm air mass transported by this storm produced significant, localized melt of sea ice, and a dynamical retreat of the ice edge.

SUSTAINABLE LAND IMAGING

The Sustainable Land Imaging (SLI) program enables the development of a multi-decade, spaceborne system that will provide U.S. users with high quality, global, land-imaging measurements. These measurements will be compatible with the existing 45-year Landsat record and will address near- and long-term issues of continuity risk. They will also evolve flexibly and responsibly through investment and introduction of new sensor and system technologies. Under the SLI framework, NASA will maintain responsibility for developing, launching, and initial checkout of space systems. The United States Geological Survey (USGS) will be responsible for collecting and documenting user requirements, developing the associated ground systems, operating the on-orbit spacecraft, and collecting, calibrating, archiving, processing, and distributing SLI system data to users.

Through the implementation of SLI technology activities, NASA will enable new SLI measurement technologies, capabilities, and architectures. The Sustainable Land Imaging-Technology (SLI-T) program aims to: (1) demonstrate improved, innovative, full-instrument concepts for potential infusion into the architecture and design of Landsat-10; and (2) develop technologies at the component and/or breadboard-level that have long-term potential to improve future land imaging instruments and systems significantly through substantial architecture changes. NASA will solicit (through ROSES) instrument and subsystem developments coordinated with the Landsat science community.

In order to minimize the risk of gaps while taking advantage of cost savings and capability enhancements resulting from the technology development activity outlined above, the Administration plans to make key strategic decisions on Landsat 10 payload/instrument approaches by the end of the decade, with the goal of beginning development of the Landsat 10 mission prior to the launch of Landsat 9.

Additional SLI activities support efforts to minimize costs and maximize the overall utility for U.S. users by responsibly engaging with international partners to ensure access to high-quality data and fusion of those measurements with those from the U.S. Landsat missions. In particular, NASA and USGS conducted pre-launch cross-calibration investigations with the European developers of the Sentinel-2A/B land imaging system, ensuring uniform calibration of both Landsat 8 and Sentinel-2A/B instruments to the same standards. The USGS, supported by NASA and other agencies, is serving as the primary U.S. Government point of contact to ensure access to and archiving of Sentinel-2 data products for U.S. research and operational users.

Recent Achievements

The SLI program is currently investing in six different technology investigations. Three of the investigations will inform instrument development for the design of Landsat 10 and are on track for instrument demonstrations in 2019. The other three will evolve sensor technology for use on SLI missions farther in the future (e.g., Landsat 11 and beyond). All six have completed the first year of their investigations.

The SLI program is also investing in a Multi-Source Land Imaging research program designed to advance the use of multi-source remote sensing data for land monitoring that primarily focuses on data from Landsat, Sentinel-1, and Sentinel-2. The objectives of this research are to develop algorithms and to prototype products that make use of multiple satellite sources and time series approaches. This research focuses on regional prototypes in preparation for continental and global standard products to understand the challenges associated with algorithms and processing streams that incorporate multiple satellite systems. The funding of the initial Multi-Source Land Imaging team allowed them to prototype new land and aquatic products by combining Landsat and other moderate-resolution, international sources of imagery. New products included wetland fractional water (via Landsat and Sentinel-1 radar); mapping of rice cultivation and inundation period (Landsat, Phased Array L-band Synthetic Aperture Radar (PALSAR), and Sentinel-1); improved urban mapping (Landsat, PALSAR), stand-scale forest phenology (Landsat and Sentinel 2), burned area products for southern Africa (Landsat and Sentinel-2), and improved global tree cover products (Landsat, Sentinel-1, and Sentinel-2).

OTHER MISSIONS AND DATA ANALYSIS

TOTAL SOLAR IRRADIANCE SENSOR-2 (TSIS-2)

TSIS-2 will be the follow-on to the TSIS-1 instrument. The TSIS-2 will maintain and extend the measurements of total solar irradiance and spectral solar irradiance provided by TSIS-1. NASA is planning to implement TSIS-2 as a CubeSat mission. The project will begin formulation in calendar year 2018.

Recent Achievements

NASA GSFC initiated the TSIS-2 pre-formulation work in April 2017, based on the recommendation in the National Academies 2007 decadal survey, for sustained multi-decadal global measurements of solar irradiance. Given the history and heritage of the SOlar Radiation and Climate Experiment (SORCE), Total solar irradiance Calibration Transfer Experiment (TCTE) and TSIS-1 instrument developments at the Laboratory for Astronomy and Space Physics (LASP) in Boulder, CO, the TSIS-2 pre-formulation team issued two separate study contracts with LASP to study different implementation approaches for TSIS-2. NASA will use the results of the study reports to determine the path forward for TSIS-2.

EARTH RADIATION BUDGET SCIENCE

The Earth Radiation Budget Science (ERBS) project produces climate data records of Earth’s radiation budget and the associated cloud, aerosol, and surface properties. The project utilizes data from the multiple radiation budget instruments in orbit as well as ancillary measurements to produce data products, which are integrated and self-consistent over the entire suite of radiation budget instruments. In addition to the five currently operating Clouds and the Earth's Radiant Energy System (CERES) instruments measuring broadband radiative fluxes from the Terra, Aqua, and Suomi NPP platforms, the data products utilize coincident imager measurements from Terra, Aqua, Suomi NPP, and operational geostationary satellite observations. In total, 13 instruments on eight spacecraft produce an accurate and temporally consistent description of the radiation budget, not only at the top of the atmosphere but also at the surface and within the atmosphere.

Recent Achievements

In 2017, the CERES team published 35 journal articles describing CERES algorithms and validation results, and made 65 code deliveries to the NASA Langley Atmospheric Science Data Center. The team supported inter-comparison campaigns between Terra, Aqua, and S-NPP, and additional campaigns with the Scanner for Radiation Budget (ScaRaB) and the Geostationary Earth Radiation Budget (GERB) instruments. They generated sensor gain and spectral response function correction coefficients for the Edition 3 forward processing and Edition 4 reprocessing, and performed validation studies and anomaly trends to evaluate the CERES data products. The CERES team completed instrument data processing software modifications and delivery to accommodate CERES Flight Model 6 (FM6) on JPSS-1 satellite, which launched in November 2017. The CERES team also modified the data product production code to utilize an updated version of the Moderate Resolution Imaging Spectroradiometer (MODIS) cloud data, and developed an improved version of the algorithm for the short-wave channel. The team completed implementation and deployment of a new system for running data production jobs, improving maintainability, and monitoring capability. The reprocessed and released Energy Balance and Filled (EBAF) data products contain significant improvements, and are the most popular CERES data products.

OTHER MISSIONS AND DATA ANALYSIS

OZONE MAPPING AND PROFILER SUITE LIMB SOUNDER (OMPS-L)

The advanced Ozone Mapping and Profiler Suite (OMPS) tracks the health of the ozone layer and measures the concentration of ozone in the Earth's atmosphere. OMPS consists of three spectrometers: a downward-looking nadir mapper, nadir profiler, and limb profiler. The entire OMPS suite currently operates on the Suomi NPP spacecraft, and to ensure data continuity, a copy of this suite will fly on NOAA's JPSS-2 mission, planned for launch in 2021. NASA is responsible for providing the OMPS-Limb profiler for integration on the OMPS instrument. NASA will also plan for future OMPS-Limb profilers on future JPSS missions.

Recent Achievements

The NASA OMPS-Limb subassembly continues to make progress in support of the NOAA JPSS-2 OMPS instrument. The pre-critical design review interface control document and mechanical interface control document were completed. The Focal Plane Assembly (FPA) was completed and delivered. The OMPS-Limb subassembly has successfully completed thermal vacuum testing and remains on track for delivery to OMPS integrated sensor integration and test in 2018. Planning for the OMPS instrument includes delivery to JPSS-2 in 2019.

Initial planning for OMPS-Limb for future JPSS missions has begun, including the procurement of long-leads parts.

TOTAL SOLAR IRRADIANCE SENSOR-1 (TSIS-1)

The TSIS-1 mission will provide absolute measurements of the total solar irradiance (TSI) and spectral solar irradiance (SSI), important for accurate scientific models of climate change and solar variability. TSIS is comprised of two instruments, the Total Irradiance Monitor (TIM), and the Spectral Irradiance Monitor (SIM). TSIS-1 launched successfully to the ISS on December 15, 2017. LASP built a highly sensitive thermal pointing system that the project will use to accommodate the instruments on the ISS. Currently, the data from an earlier NASA-managed TIM instrument, flying on the aging SORCE spacecraft, launched in 2003, provides the TSI data record as part of an unbroken 36-year long data record. The Total Solar Irradiance Calibration Transfer Experiment (TCTE) instrument, a joint mission with NOAA and the U.S. Air Force, launched in 2013 and currently augments the data record. The TSIS-1 project transferred fully to NASA in FY 2016 and NASA installed it on the ISS in FY 2018 in time to overlap with the TCTE mission in order to maintain continuity of the solar irradiance measurement.

NASA assumed responsibility for TCTE operations from NOAA in January 2018.

Recent Achievements

The TSIS-1 project completed the integration of the TIM and SIM onto the TPS and successfully conducted environmental testing of the complete payload. The project transported the payload to Kennedy Space Center in August to finalize the pre-launch testing and wait for launch, still scheduled for late calendar year 2017 on the SpaceX-13 resupply mission to ISS. Astronauts will install the payload on the ISS and it will undergo three months of commissioning before entering operations in FY 2018.

OTHER MISSIONS AND DATA ANALYSIS

DECADAL SURVEY MISSIONS

The Decadal Survey project contains missions recommended by the National Academies Earth Science decadal survey. All the missions within this project are in a pre-formulation phase conducting mission concept studies. The latest Decadal Survey released in January 2018 will guide the selection of future pre-formulation studies. The current portfolio of missions under study includes:

- CLARREO;
- Active Sensing of CO2 Emissions over Nights, Days, and Seasons (ASCENDS);
- GEOstationary Coastal and Air Pollution Events (GEO-CAPE);
- ACE; and
- Hyperspectral Infrared Imager (HyspIRI).

Recent Achievements

Mission teams continue to make progress in requirements refinement and modeling, instrument concept and technology maturation, and algorithm development.

EARTH SCIENCE PROGRAM MANAGEMENT

- The Earth Science Program Management budget supports critical flight project management functions executed by the ESM Program Office at GSFC, the Earth System Science Pathfinder Program Office at LaRC and the Earth Science Flight Project Office at JPL. This budget also supports:
- The GSFC conjunction assessment risk analysis function, which determines maneuvers required to avoid potential collisions between spacecraft and to avoid debris;
- The technical and management support for the international Committee on Earth Observation Satellites, which coordinates civil space-borne observations of Earth. Participating agencies strive to enhance international coordination and data exchange and to optimize societal benefit;
- Senior Review Board teams, who conduct independent reviews of the various flight projects in Earth Science;
- Earth Science division communications and public engagement activities.

PRECIPITATION SCIENCE TEAM

The Precipitation Science Team carries out investigations of precipitation using measurements from, but not limited to, TRMM whose mission ended in 2015, the GPM Core Observatory launched in February 2014, and GPM mission constellation partner spacecraft (partners include NOAA, DoD, CNES, (JAXA), and EUMETSAT. This program supports scientific investigations in three research categories:

- Development, evaluation, and validation of TRMM and GPM retrieval algorithms;
- Development of methodologies for improved application of satellite measurements; and
- Use of satellite and ground measurements for physical process studies to gain a better understanding of the global water cycle, climate, and weather and concomitant improvements in numerical models on cloud resolving to climate scales.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

Researchers used GPM Ku radar data to classify the largest, deepest, and strongest precipitation systems on Earth. The study noted that with the GPM-CO's higher latitude coverage, DPR reveals that precipitating storm systems in the Great Plains of the U.S. and Argentina are among the most intense on Earth. An analysis of GPM data shows an improved representation of monsoon precipitation and its interaction with atmospheric dynamics over West Africa. Researchers also developed short-term forecasts of soil moisture and other parameters to understand better the land-atmosphere interactions on scales of days to years, and the forecasts are available from the NASA Land Information System based on GPM data along with other precipitation data. These studies have shown that increased land surface model grid resolution (~1 km) can yield an improvement in the estimation of surface model water balance. GPM's data for extreme precipitation leading to flood or landside events, and the characterization of potential hazards, are a source of several GPM investigations. GPM's precipitation products continue to inform scientific studies and benefit societal application activities.

As pioneered by the legacy NASA Tropical Rainfall Measuring Mission (TRMM), quasi-global, long-record, fine-scale precipitation estimates based on a merged combination of all precipitation-relevant satellites from around the world have rapidly become the go-to product for many precipitation-based applications in the U.S. and internationally. GPM provides this data product at temporal scales of 30 minutes and spatial resolutions of 10 km by 10 km, and is in the process of unifying the TRMM and GPM precipitation estimates to create a 20+ year record. Near-real-time data are key to short-fuse applications, including the Global Flood Monitor for flood analysis and the Potential Landslide Areas site for precipitation-driven landslides. These data continue to be widely used in the disaster response community, including the NASA disaster response activity, World Bank, and International Red Cross.

OCEAN WINDS SCIENCE TEAM

The Ocean Winds Science Team (OWST) uses scientific data received from the QuikSCAT satellite, RapidScat instrument, and other international missions, which measure ocean surface winds by sensing ripples caused by winds at the ocean's surface. From this data, scientists can compute wind speed and direction thus acquiring global observations of surface wind velocity each day. The sparse wind data from ships and buoys serve to calibrate the satellite data.

Recent Achievements

Several dozen scientific publications appeared in the literature over the past 12 months using data from QuikSCAT together with either in situ data or other satellite scatterometers, to study ocean winds, sea ice extent, various polar applications, canopy water content, and snow depth. Progress has been in understanding meso-cyclones in high latitudes, which are important maritime atmospheric phenomena, but generally difficult to track in global reanalysis due to their small size (200-1000 km) and short lifetime (6-36). New studies are now using manual techniques to track meso-cyclones over the Southern Ocean during winter using QuikSCAT observations. The use of the QuikSCAT data provided insights into physics of mid-latitude storms, highlighting the importance of wind convergence over the storm tracks, such as the Gulf Stream. The energy sector successfully exploited the use of scatterometer data, with recommendations for development of specific wind turbines over the Mediterranean Sea, based on the available offshore wind resource potential and the water depth suitability.

OTHER MISSIONS AND DATA ANALYSIS

LAND COVER PROJECT SCIENCE OFFICE

The Land Cover Project Science Office (LCPSO) maintains over 40 years of calibration records for the Landsat 1 through Landsat 8 series of satellites. The office also provides community software tools to make it easier for users to work with this data. In collaboration with USGS, LCPSO supports cross-calibration of the Landsat record with other international sensors, provision of preprocessed data sets for land-cover change analysis, and facilitates use of international data sets for improved land cover monitoring.

Recent Achievements

A recent focus of the LCPSO has been to prepare the U.S. land cover research community for the integration of European Sentinel-1 and Sentinel-2 datasets into land monitoring activities. The LCPSO has expanded development of the Harmonized Landsat/Sentinel-2 (HLS) dataset, which provides a seamless record of surface reflectance derived from both sensors. LCPSO is upgrading the initial dataset to provide wall-to-wall coverage across North America. Additionally, LCPSO continues to support Committee on Earth Observation Satellite initiatives within NASA, including the Land Surface Imaging Virtual Constellation, the Moderate Resolution Interoperability initiative, and the Working Group on Calibration/Validation.

OCEAN SALINITY SCIENCE TEAM

The Ocean Salinity Science Team (OSST) supports the development and construction of surface salinity products from L-Band microwave radiometers such as Aquarius, SMAP, and data sets of opportunity such as ESA’s Soil Moisture and Ocean Salinity (SMOS) mission. The team also seeks to understand upper-ocean processes that impact variability of surface salinity in order to improve interpretation of the space-based salinity products. The team is working on a SMAP salinity product that is consistent with the Aquarius salinity product, which ended in June 2015.

Recent Achievements

OSST produced global maps of the ocean salinity with unprecedented coverage, accuracy, and resolution, which have boosted oceanographic research and improved our understanding of various climate phenomena, including the El Nino-Southern Oscillation, the monsoons, the tropical instability waves, the Madden-Julian Oscillations, and the ocean fingerprints of the tropical cyclones and excessive river runoffs. In addition, by utilizing ocean salinity data from Aquarius, SMAP, and in situ platforms, researchers are gaining improved insights into the causes of the recent changes in the Earth’s water budget. New studies reveal the global amplification of the ocean water cycle (the amount of freshwater leaving and entering the oceans via the processes of evaporation, precipitation, and runoff), with a general tendency of drying of arid subtropical ocean regions and wetting in the tropical and mid-to-high-latitude latitudes over the past two decades. Such tendency has potential impacts on the continental floods and droughts. By using high-quality salinity observations, researchers are now linking salinity changes with the global ocean water cycle and ocean circulation, improving our predictive capability of climate processes.

OTHER MISSIONS AND DATA ANALYSIS

Operating Missions

SOIL MOISTURE ACTIVE AND PASSIVE (SMAP)

The SMAP mission provides a capability for global mapping of soil moisture with unprecedented accuracy, resolution, and coverage. The SMAP measurement system consists of a radiometer (passive) instrument and a synthetic aperture radar (active) instrument operating with multiple polarizations in the L-band range. Although the active radar instrument failed in July 2015, the radiometer is operating nominally, and continues to provide global mapping of soil moisture with accuracy, resolution, and coverage that exceeds the capability of other on-orbit systems.

SMAP's prime mission will end in June 2018. The 2017 Earth Science senior review endorsed the SMAP mission for continued operations through 2020, and preliminarily, through 2023.

Recent Achievements

In 2017, SMAP combined its passive radiometer data with radar data from the European Copernicus Sentinel-1 mission to generate a preliminary version of a 3-km resolution soil moisture data product. The assimilation of SMAP soil moisture products into the US Department of Agriculture's Foreign Agriculture System also helped to improve estimates of future vegetation health. The L-band brightness temperatures have been used to retrieve sea surface salinity over open water, which, when combined with soil moisture, shed light on the linkage between the land and ocean branches of the water cycle, and how the ocean ecosystem in the Gulf of Mexico might be influenced by freshwater from river discharge. The 2017 Atlantic hurricane monitoring and trending activities used SMAP-derived ocean wind speeds.

GLOBAL PRECIPITATION MEASUREMENT (GPM)

The GPM mission advances the measurement of global precipitation through the combined use of active and passive remote-sensing techniques. Tracking storms as they move into the mid-latitudes, GPM provides a three-dimensional view of their structural changes as they move toward the poles, offering insight into why some, but not all, storms change intensity as they move. The GPM Microwave Imager (GMI) measures energy from different types of precipitation through clouds, to estimate heavy to light rain and to detect falling snow. The Dual-frequency Precipitation Radar (DPR) provides three-dimensional information about precipitation particles, including their size distributions, derived from reflected energy at different heights within the cloud system. GPM is a joint mission with the Japan space agency, JAXA.

GPM completed its prime mission in June 2017, and is now in extended operations. The 2017 Earth Science senior review endorsed the GPM mission for continued operations through 2020, and preliminarily, through 2023.

Recent Achievements

In 2017, GPM completed its prime operations phase and demonstrated that all Level-1 requirements have been satisfied. GPM's program of research has been able to not only detect falling snow, but has yielded important progress in estimating falling snow rates at the Earth's surface and in the atmosphere. Scientists have made significant progress in improving the accuracy of precipitation retrievals over land surfaces, thus providing valuable data to agricultural and other users. The project released two new data visualization tools, including the Global Viewer for viewing near real-time global precipitation data, and the Precipitation and Applications Viewer for recent (30 minute, one-day, three-day, and seven-day) precipitation, flood, and landslide data. Fire susceptibility mapping now includes GPM data. GPM provided short, informative social media and featured articles about current weather events, especially the 2017 Atlantic Hurricane season (e.g., Harvey, Irma, Jose, Maria) as depicted in GPM data products that are aimed at the general public, as well as weather and application specialists.

LANDSAT 8

Landsat 8 is the most recent in the Landsat series of satellites that have been continuously observing Earth's land surfaces by recording data since 1972. In addition to widespread routine use for land use planning and monitoring on regional to local scales, support of disaster response and evaluations, and water use monitoring, Landsat 8 measurements directly serve NASA research in the focus areas of climate, carbon cycle, ecosystems, water cycle, biogeochemistry, and Earth surface/interior. USGS performs mission operations for Landsat 8, but NASA provides science activities in support of the USGS and the Landsat Science Team during prime mission operations.

Recent Achievements

In 2017, Landsat 8 passed 1 million scenes acquired since launch in 2013. The Landsat 8 Thermal Infrared Sensor (TIRS) provided the first views of the breakup of the Larsen C Ice Shelf in Antarctica, and continued to provide imagery throughout the southern hemisphere winter. This allowed researchers to study the mechanics of ice shelf breakup at high spatial and temporal resolution. With support from both USGS and NASA, a team from Rochester Institute of Technology (RIT) developed an algorithm to improve the quality TIRS data, including correcting a stray light issue that affects the radiometric quality of one band using other information from the Landsat 8 image. The correction has now been included in the Landsat 8 processing system at the USGS Earth Resources Observation and Science (EROS) center. The NASA team continued to refine the radiometric calibration for both TIRS and the Operational Land Imager (OLI) instruments, with a particular focus on calibration with the ESA Sentinel-2 constellation. Results indicate that both OLI and Sentinel-2 MultiSpectral Instrument (MSI) data are quite consistent, and both meet their absolute radiometry requirements. This cross calibration has allowed combined use of both data sets for land monitoring, including merged datasets such as the Harmonized Landsat/Sentinel-2 (HLS) surface reflectance data set produced at GSFC.

OCEAN SURFACE TOPOGRAPHY MISSION (OSTM)

OSTM, or OSTM/Jason-2, measures sea surface height, and enables scientists to track changes in ocean currents, assess climate variability, and make improved maps of the sea floor. This mission is the third in a series of ocean surface topography missions (following Jason-1 and TOPEX/Poseidon) followed by Jason-3, launched in January 2016. After the launch of Jason-3, Jason-2 moved into a new orbit configuration with very closely spaced ground tracks that scientists now use to better understand gravity over the ocean, and make improved maps of the sea floor. OSTM/Jason-2 is a joint mission with NOAA, CNES, and the European meteorological satellite agency (EUMETSAT).

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

In 2017, the OSTM/Jason-2 mission moved to a new orbit configuration that alternates between its original orbit and that of Jason-3. This new orbit significantly improved the resolution for observations of ocean currents and climate variability, and improved the forecasting of ocean currents, marine wind and wave conditions, and hurricane intensity by various domestic agencies. During FY 2017, aging of spacecraft components necessitated a third orbit configuration. This new "geodetic" orbit phase repeats only once per year and has very closely spaced ground tracks. This data is now being used by scientists to improve the marine geoid and to make improved maps of the sea floor, and to chart small to mid-sized seamounts (underwater mountains), tens of thousands of which had been previously been uncharted. The OSTM/Jason-2 geodetic mission phase has already yielded significant improvements in the marine gravity field and the completion of its first geodetic cycle remains the top scientific priority for OSTM in its continuing mission. These improvements to bathymetry (measurement of water) and mean sea surface models will be of great scientific benefit to the upcoming (SWOT mission scheduled for launch in 2021.

SUOMI NATIONAL POLAR-ORBITING PARTNERSHIP (SUOMI NPP)

NASA built and launched Suomi NPP. NOAA operates the spacecraft and instruments. The five instruments on Suomi NPP provide visible and infrared multi-spectral global imagery, atmospheric temperature and moisture profiles, total ozone and stratospheric ozone profiles, and measurements of Earth's radiation balance. In addition to a wide range of applications studies, the NASA science focus areas served by Suomi NPP include atmospheric composition, climate variability and change, carbon cycle, ecosystems, water and energy cycles, and weather. NASA and NOAA continue to collaborate to ensure meeting the shared objectives of both agencies. Prime mission operations officially ended in March 2017, and Suomi NPP is currently in extended operations until "fill in the date".

Recent Achievements

The Suomi NPP End of Prime Mission review concluded in October 2017, and the material presented demonstrated that the mission has met its Level-1 requirements. The multi-satellite ocean color data record, now extended with the Visible Infrared Imaging Radiometer Suite (VIIRS), shows the recovery of chlorophyll-a after the recent El Nino event. The routine assimilation of Suomi NPP data into NOAA models improved forecasts of extreme events, such as Hurricanes Harvey, Irma, and Maria. NASA's Black Marble High Definition products supported 2017 hurricane recovery efforts. This dataset combined data from six satellites to enable the first-ever monitoring of affected areas at neighborhood (< 30 meter) scales. The Suomi NPP mission also provided near-real-time observations of recent severe wildfires in California and Canada, with the Ozone Mapping Profiler Suite (OMPS) measuring the highest Aerosol Index (a measure of particulate matter intensity) on record. Combined use of VIIRS and OMPS aerosol data allowed determination of the height of this smoke. This multi-sensor synergy showed that these fires were so intense that some of the smoke entered the stratosphere, which has important climate implications.

TERRA

Terra is, one of the EOS flagship missions. It enables a wide range of interdisciplinary studies of atmospheric composition, carbon cycle, ecosystems, biogeochemistry, climate variability and change, water and energy cycles, and weather. The Terra mission has provided more than 18 years of continuous data collection, including fundamental observations of the Earth's climate system, high-impact events, and adding value to other satellite missions and field campaigns. The spacecraft platform and five sensors are all fully functional, with the exception of the Shortwave Infrared (SWIR) bands in the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument. Terra is a joint mission with Japan and Canada.

Recent Achievements

In 2017, Terra's sensors provided key observational (and analyses) data for several natural hazard events, such as Hurricanes Harvey, Irma, and Maria, along with the devastating wildfires in the Western US-Canada and South Africa; volcanic eruptions in various parts of the world from Eastern Siberia to Mexico and Peru, and fierce dust storm outbreaks from Western China to the Mid-East. Release of Version 3 of the ASTER Global Digital Elevation Model (GDEM) makes it the most complete, consistent high-resolution global topographic data set ever released to the public. The mission generated near-real-time aerosol, fire, and carbon monoxide products that were used to understand health, air quality and safety impacts, while its near-real-time wind and cloud data were included in weather service forecasts. Terra conducted a complete reprocessing of multiple data products over the mission's lifetime, to include updated sensor knowledge, and performed a maneuver allowing its sensors to view the moon as one of the means to improve agreement among Terra's sensors, as well as with sensors on other platforms.

AQUA

Aqua, one of the EOS flagship missions, improves our understanding of Earth's water cycle and the intricacies of the climate system by monitoring atmospheric, land, ocean, and ice variables. It was the first satellite launched into what has become the afternoon constellation of satellites, known as the A-Train, and remains the anchor satellite of that constellation. Four of Aqua's Earth observing instruments – the Atmospheric Infrared Sounder (AIRS), the Advanced Microwave Sounding Unit (AMSU), Clouds and the Earth's Radiant Energy System (CERES), and the Moderate Resolution Imaging Spectroradiometer (MODIS) – continue to collect valuable data about the Earth's atmosphere, oceans, land, ice, and overall energy budget. These data are widely used by the science community, and in practical applications ranging from improved weather forecasting to monitoring forest fires, crop yields, volcanic ash plumes, and ice-infested waters. Aqua is a joint mission with Japan and Brazil.

Aqua is currently in extended operations. The 2017 Earth Science senior review endorsed the Aqua mission for continued operations through 2020, and preliminarily, through 2023.

Recent Achievements

In 2017, studies based on Aqua data shed light on the intricate links between clouds, aerosols, and rainfall. Aqua data supported determination of the properties of aerosols near clouds, the extent to which warm (liquid) cloud properties respond to sulfuric aerosols, why drizzle from these clouds differs between land and ocean, and how global rainfall will likely respond to future warming. Combined with ground-based lightning networks, Aqua data also showed that lightning storms were the main driver of recent massive fire years in Alaska and northern Canada, while another study showed that burned areas decreased overall because of anthropogenic activity. Data from Aqua's AIRS instrument also revealed global airborne ammonia gas trends and "hotspots" of the pollutant in four of the world's most productive agricultural regions. Aqua's contributions to practical applications in 2017 included monitoring of Hurricane Harvey as it evolved and identifying the location of the strongest storms spawned by Hurricane Maria.

OTHER MISSIONS AND DATA ANALYSIS

AURA

Aura, one of the EOS flagship missions, advances the understanding of changes in the Earth's radiation balance, air quality, and the ozone layer that result from changes in atmospheric composition, climate variability, and weather by measuring atmospheric chemical composition, tropospheric/stratospheric exchange of energy and chemicals, chemistry-climate interactions, and air quality. Aura is also part of the A-Train. Three of Aura's four instruments are operational: the Microwave Limb Sounder (MLS), the Ozone Monitoring Instrument (OMI), and the Tropospheric Emission Spectrometer (TES). Additional measurements include clouds, aerosols, solar spectral irradiance, and water vapor. Aura is a joint mission with the Netherlands, Finland, and the United Kingdom.

Aura is currently in extended operations. The 2017 Earth Science senior review endorsed the Aura mission for continued operations through 2020, and preliminarily, through 2023.

Recent Achievements

Exploiting the long-term Aura record enabled scientists to estimate the impacts of air quality on human health. In 2017, Aura observations informed estimates of the cancer risk in the southeastern US from exposure to outdoor formaldehyde, a by-product of natural compounds emitted from trees. Its measurements of nitrogen dioxide, a pollutant emitted during combustion, and formaldehyde, were capable of assisting air quality managers in assessing the most effective approaches to emission reduction programs that will improve air quality. Aura's measurements of ozone and hydrochloric acid supported characterization of an unprecedented disruption to the quasi-biennial oscillation (QBO), a naturally occurring meteorological phenomenon, which is a leading driver of stratospheric composition variability. Incorporation of Aura's stratospheric column ozone data into the operational ozone assimilation occurred at the NOAA National Centers for Environmental Prediction (NCEP) for weather and UV Index forecasts.

SOLAR RADIATION AND CLIMATE EXPERIMENT (SORCE)

The SORCE mission measures the total and spectral solar irradiance incident at the top of the Earth's atmosphere. SORCE measurements of incoming X-ray, ultraviolet, visible, near infrared, and total solar radiation help researchers to understand natural variability in atmospheric ozone and ultraviolet-B radiation, thus leading to enhanced climate prediction models. These measurements are also critical to studies of the Sun, its effect on the Earth system, and its influence on humankind.

SORCE is currently in extended operations. The 2017 Earth Science senior review endorsed the SORCE mission for continued operations through 2019, and possibly 2020, to ensure an overlap with the TSIS mission.

Recent Achievements

Collecting accurate TSI (total solar irradiance) and SSI (solar spectral irradiance) data spanning multiple years helps scientists understand how much solar radiation is deposited in the atmosphere and at the surface and thus how much energy is available to influence weather, climate, the cryosphere, atmosphere dynamics, and ocean currents. In 2017, the SORCE mission extended the uninterrupted TSI record to 38 years. The project established a new 15-year SSI record for the near ultraviolet, visible, and near infrared wavelength ranges that together comprise almost 95 percent of the Sun's total energy. Important in these solar records is the amount by which the TSI and SSI increase and decrease over an 11-year period, known as the solar activity cycle. Global energy-balance estimates and climate studies use the SORCE TSI. TSI's high sensitivity allowed SORCE to detect three Mercury transit events that decreased the sunlight at the Earth by ~0.004 percent.

STRATOSPHERIC AEROSOL AND GAS EXPERIMENT III (SAGE-III)

The Stratospheric Aerosol and Gas Experiment III (SAGE-III) provides global, long-term measurements of key components of Earth's atmosphere. The most important of these are the vertical distribution of aerosols and ozone from the upper troposphere through the stratosphere. In addition, SAGE-III provides unique measurements of temperature in the stratosphere and mesosphere and profiles of trace gases, such as water vapor and nitrogen dioxide, which play significant roles in atmospheric radiative and chemical processes. These measurements are vital inputs to the global scientific community for improved understanding of climate and human-induced ozone trends.

Recent Achievements

SAGE-III successfully launched and installed on the International Space Station (ISS) in February 2017. Commissioning completed in June 2017, and the initial release of data occurred in October 2017.

EARTH FROM ISS

NASA's ISS program sponsored the development of several earth science instruments for the ISS. The Earth from ISS project will ensure the appropriate processing of data and its availability to the earth science research community from the data collected by these instruments. This project will invest in algorithm development, data production, and distribution, as well as data analysis and modeling for the currently planned ISS earth science payloads.

The ISS Cloud Aerosol Transport System (CATS) is a lidar remote sensing instrument using a laser to provide detailed information about cloud and aerosol presence, height, and composition. CATS demonstrates new technologies and generates data useful for improving our understanding of aerosol and cloud properties and interactions. Since beginning science operations in 2015, the CATS laser has generated an unprecedented 200 billion laser shots. As a technology demonstration using solid-state lasers for spaceborne remote sensing, CATS far exceeded expectations and provides a solid pathway to low risk, high quality next-generation remote sensing of cloud and aerosol properties. The 2017 Earth Science senior review endorsed the CATS mission for continued operations through 2020.

The ISS Lightning Imaging Sensor (LIS) makes space-based global lightning observations, using the backup flight spare for the instrument that operated for 17 years on the Tropical Rainfall Measuring Mission (TRMM). Launched in February 2017, LIS provides a great opportunity to not only extend the TRMM record of tropical lightning measurements, but also to expand coverage to the higher latitudes missed by the previous mission. LIS observations continue to support, and are used by, the global scientific research community, across a wide range of disciplines that include weather and extreme storms, climate studies, atmospheric chemistry, and lightning physics. LIS can also help calibrate and validate the observations from the new Geostationary Lightning Mapper (GLM) operating on NOAA's newest geostationary weather satellite, GOES-16.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

One strength of RapidScat was its ability to detect the diurnal cycle of wind over the oceans. New studies demonstrate the use of RapidScat, together with data from international platforms such as OceanSat2, Windsat, and Scatsat, to detect sub-diurnal (half a day) variability in the tropical Pacific Ocean, which improves our understanding of major climate phenomena, such as El Nino-Southern Oscillation. RapidScat's ability to capture the diurnal cycle also allowed research to interpret the signals on the global coasts more accurately, properly distinguishing between the annual and diurnal variability.

Scientists use CATS data in operational aerosol forecast models to improve air quality prediction and monitoring, and to improve hazard-warning capabilities for natural events (e.g., dust storms and volcanic eruptions). Multiple users, including NASA's Global Modeling and Assimilation Office (GMAO), NRL, European Centre for Medium-Range Weather Forecasts (ECMWF), Air Force Weather, and UK Met Office are actively engaged in using CATS data to improve aerosol and air quality forecasting. Volcanic plume tracking and monitoring and smoke plume tracking from large wildfires benefitted from improvements in forecast models, resulting from the use of CATS data.

The LIS instrument launched to the ISS in February 2017. Since its installation on the ISS, LIS has been continuously acquiring global lightning observations. The science and operations team for LIS successfully conducted the Post Launch Assessment Review (PLAR) in October 2017. Based on its successful on-orbit operations and its compliance with Level-1 science requirements, LIS entered the operational phase. Planning for a new release of the LIS science data is set for late CY 2017. Near-real-time (two minute) processing has been successful since mission start, and that data will be made available to interested users to complement operational forecast and aviation applications in data sparse regions such as over the ocean.

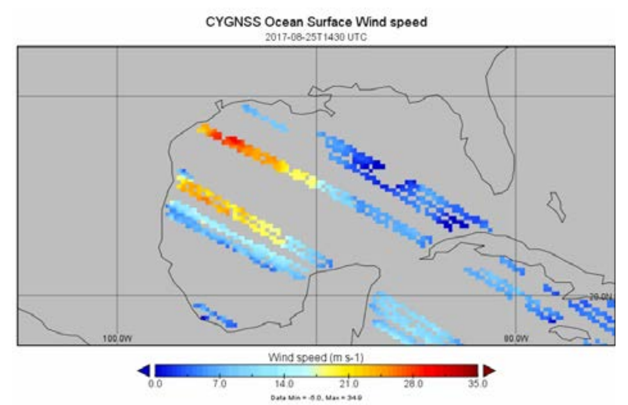
EARTH SYSTEM SCIENCE PATHFINDER

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Venture Class Missions	146.6	--	**167.5**	205.2	199.1	204.0	213.4
Other Missions and Data Analysis	62.3	--	**67.5**	68.6	69.0	70.3	74.3
Total Budget	**208.8**	**--**	**235.0**	**273.7**	**268.2**	**274.3**	**287.7**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



This data product generated from CYGNSS shows surface wind speed prior to the landfall of Hurricane Harvey on 26 Aug 2017. Hurricane Harvey is centered slightly off-shore, in the region of highest wind speeds shown in red.

The Earth Science System Pathfinder (ESSP) program provides frequent, regular, competitively selected Earth science research opportunities that accommodate new and emerging scientific priorities and measurement capabilities. This results in a series of relatively low-cost, small-sized investigations and missions. Principal investigators whose scientific objectives support a variety of studies lead these missions, including studies of the atmosphere, oceans, land surface, polar ice regions, or solid Earth.

ESSP projects include space missions and remote sensing instruments for space-based missions of opportunity or extended duration airborne science missions. The ESSP program also supports the conduct of science research utilizing data from these missions. ESSP projects often involve partnerships with other U.S. agencies and/or international organizations. This portfolio of missions and investigations provides opportunity for investment in innovative earth science that enhances NASA’s capability for better understanding the current state of the Earth system.

EXPLANATION OF MAJOR CHANGES IN FY 2019

The Budget proposes to cancel the Orbiting Carbon Observatory-3 (OCO-3) project and place the instrument hardware in storage. Carbon dioxide measurements are currently being taken by NASA’s OCO-2 mission as well as the Japanese GOSAT satellite. Future measurements of carbon dioxide are planned by Japan and the European Space Agency.

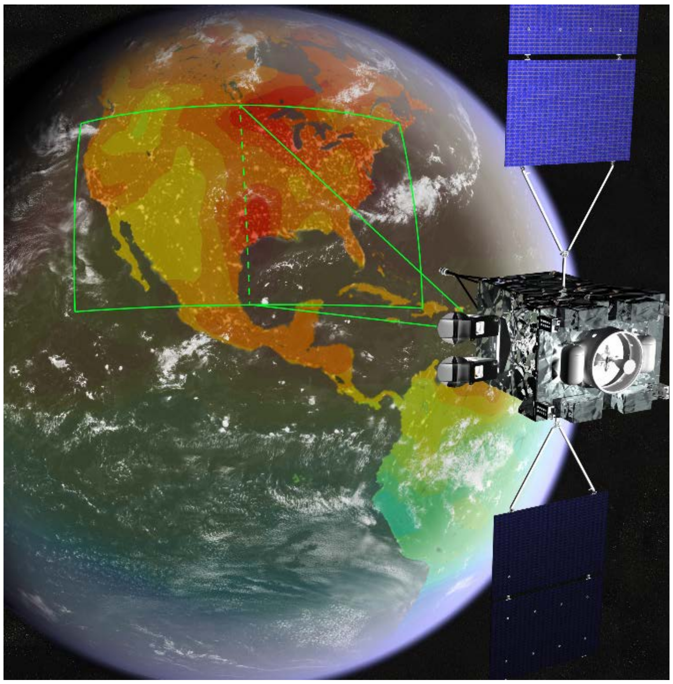
VENTURE CLASS MISSIONS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	146.6	--	167.5	205.2	199.1	204.0	213.4

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



Measurements from NASA's Earth Venture Mission-II, GeoCarb, will change our understanding of the carbon cycle's terrestrial source/sink dynamics by providing high-spatial resolution daily mapping from geostationary orbit of the carbon dioxide, methane, and carbon monoxide over much of the Americas. GeoCarb will help us understand why the global Carbon Cycle is changing, how gas emissions that trap heat vary with population, and how variations in the biosphere affect the natural uptake and emissions of carbon dioxide and methane.

NASA's Earth Venture Class Missions provide frequent flight opportunities for high-quality, low-cost earth science investigations that can be developed and flown in five years or less. NASA selects the investigations through open competitions to ensure broad community involvement and encourages innovative approaches. Successful investigations enhance our capability to understand the current state of the Earth system and enable continual improvement in the prediction of future changes. Solicitations will alternate between space-borne and airborne/suborbital opportunities.

NASA established the Venture Class project in response to recommendations in the 2007 National Academies' report, Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond. The 2017 National Academies' report, Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space, also endorses the Venture Class project.

VENTURE CLASS MISSIONS

The Earth Venture Class Missions include three components:

- Earth Venture Suborbital (EVS) investigations, which are sustained suborbital science investigations. NASA releases EVS solicitations every four years with a cost cap up to $150 million in FY 2014 dollars, and selects multiple investigations within each call, individually capped up to $30 million.

- Earth Venture Missions (EVM) are small space-based missions. NASA releases EVM solicitations every four years at a cost cap up to $166 million in FY 2018 dollars.

- Earth Venture-Instruments (EVI) will fly on space-borne platforms. NASA releases EVI solicitations every 18 months at a cost cap up to $97 million in FY 2018 dollars.

EXPLANATION OF MAJOR CHANGES IN FY 2019

The EVI-2 Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) reduced the number of CubeSats planned for its constellation from twelve (12) to six (6) based on the PI's assessment of mission implementation approaches to meet the science requirements.

ACHIEVEMENTS IN FY 2017

EVS:

The EVS-2 successfully deployed all planned missions for FY 2017. These missions include the following:

Atmospheric Carbon and Transport America (ACT-America) to the eastern and central U.S. during quarterly report two (Q2)

Atmospheric Tomography Mission (ATom) on a global transit during Q2

COral Reef Airborne Laboratory (CORAL) to Australia's Great Barrier Reef during Q1, Hawaii during Q2, and the Marianas Islands, Palau and the Florida Keys during Q3

North Atlantic Aerosols and Marine Ecosystems Study (NAAMES) to the North Atlantic/St. John's Newfoundland in Q4

Oceans Melting Greenland (OMG) to Iceland, Norway and Greenland in Q2 and in Q4

ObseRvations of Aerosols above CLouds and their intEractionS (ORACLES) to São Tomé and Principe Africa in Q4

EVM:

In December 2016, NASA launched the Cyclone Global Navigation Satellite System (CYGNSS) project.

VENTURE CLASS MISSIONS

NASA awarded the Geostationary Carbon Cycle Observatory (GeoCarb) contract to the University of Oklahoma and approved the mission to enter formulation, Phase A.

EVI:

The Global Ecosystem Dynamics Investigation (GEDI) project completed its Critical Design Review (CDR) and initiated hardware procurement and manufacturing activities and integration and subsystem testing.

The Multi-Angle Imager for Aerosols (MAIA) project completed its System Requirements Review (SRR), passed its KDP-B review, and entered its preliminary design and technology completion activities phase.

TROPICS completed its SRR and passed KDP-Band entered its preliminary design and technology completion activities phase.

WORK IN PROGRESS IN FY 2018

EVS:

The CORAL mission will complete KDP-F, and execute project closeout activities. The remaining five EVS-2 missions (ACT-America, Atom, NAAMES, OMG, and ORACLES) will continue data collection. NASA plans to release the solicitation for EVS-3.

EVM:

The CYGNSS project is in its operation and sustainment phase, Phase E, and providing measurements of ocean surface winds.

The GeoCarb project will complete SRR, pass its KDP-B review, complete its Preliminary Design Review (PDR), and pass its KDP-C review.

EVI:

The Tropospheric Emissions: Monitoring of Pollution (TEMPO) instrument will complete subsystem development and integration, initiate instrument-level testing, and continue data processing code development. NASA will release the Request for Proposal (RFP) for procuring a host and award the host services contract.

The ECOSTRESS project will complete payload development and NASA will install ECOSTRESS on the International Space Station (ISS).

The GEDI project will complete integration and begin instrument level testing.

The MAIA project will conduct its PDR, pass its KDP-C review, and enter its final design and fabrication activities phase.

The TROPICS project will complete its PDR, CDR, pass its KDP-C review, and enter its final design and fabrication activities phase.

VENTURE CLASS MISSIONS

NASA will release the EVI-5 solicitation and complete EVI-4 selection(s).

KEY ACHIEVEMENTS PLANNED FOR FY 2019

EVS:

EVS-3 investigations will begin operations.

EVM:

The Cyclone Global Navigation Satellite System (CYGNSS) project will complete its prime mission.

The GeoCarb project will complete its CDR.

EVI:

NASA plans to deliver the TEMPO instrument to storage. The project will prepare for TEMPO integration onto its host spacecraft.

The GEDI project will complete payload development and NASA will install ECOSTRESS on the International Space Station (ISS).

The MAIA project will complete its CDR.

The TROPICS project will complete its System Integration Review (SIR)/Pre-Environmental Test Review (PER) and enter final assembly and test for the constellation.

Program Elements

Venture Class Future Missions

Earth Venture Class Future Mission funding supports the selection of new missions through AO solicitations, at intervals of every four years for EVS and EVM, and every 18 months for EVI.

Cyclone Global Navigation Satellite System (CYGNSS) (EVM-1, selected in 2012)

CYGNSS performs accurate measurements of ocean surface winds throughout the life cycle of tropical storms and hurricanes, leading to better weather forecasting. CYGNSS data is enabling scientists to probe from space key air-sea interaction processes that take place near the inner core of the storms, which are rapidly changing, and play large roles in the genesis and intensification of hurricanes. The CYGNSS measurements also provides information to the hurricane forecast community, potentially enabling better modeling to predict the strength of hurricanes as they develop.

CYGNSS's eight micro-satellite observatories receive both direct and reflected signals from Global Positioning System (GPS) satellites. The direct GPS signals pinpoint CYGNSS observatory positions, while the reflected signals are indicative of ocean surface roughness. Scientists use both measurements to derive the critical measurement of wind speed. CYGNSS completed development and launched in

December 2016. CYGNSS entered the operational phase and will conduct its prime mission for 24 months.

Tropospheric Emissions: Monitoring of Pollution (TEMPO) (EVI-1, selected in 2012)

The TEMPO instrument will measure atmospheric pollution covering most of North America. A commercial communications satellite will host the instrument and launch no earlier than 2021. On an hourly basis, TEMPO will measure atmospheric pollution from Mexico City to the Canadian tar/oil sands and from the Atlantic to the Pacific. TEMPO will provide measurements that include the key elements of air pollution chemistry, such as ozone and nitrogen dioxide, in the lowest part of the atmosphere. Measurements from geostationary orbit will capture the inherent high variability in the daily cycle of emissions and chemistry. Measuring across both time and space will create a revolutionary dataset that provides understanding and improves prediction of air quality and climate forcing.

NASA will procure the commercial host spacecraft service through the United States Air Force (USAF) Space and Missile Systems Center Hosted Payload Solutions contract. In discussions with potential hosts, all identified concerns about the cost impact a late delivery by NASA would have on their spacecraft. In order to avoid the adverse pricing such risk would entail, the TEMPO project will delay the release of the RFP for hosting until after the completion of the instrument, with a projected launch date of no earlier than (NET) 2021.

Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) (EVI-2, selected in 2014)

ECOSTRESS will fill a key gap in our observing capability and advance core NASA and societal objectives. Specifically, ECOSTRESS will enable NASA to address the following science objectives:

1) Identify critical thresholds of water use and water stress in key climate sensitive biomes;

2) Detect the timing, location, and predictive factors leading to plant water uptake decline and/or cessation over the daily cycle; and

3) Measure agricultural water consumption over the contiguous United States to improve drought estimation accuracy.

ECOSTRESS will observe changes in global vegetation from the ISS. The sensors will give scientists new ways to see how changes in climate or land use change affect forests and ecosystems. ECOSTRESS will use a high-resolution thermal infrared radiometer to measure plant evapotranspiration, and the loss of water from growing leaves and evaporation from the soil. These data will reveal how ecosystems change with climate, and provide a critical link between the water cycle and effectiveness of plant growth, both natural and agricultural.

Global Ecosystem Dynamics Investigation (GEDI) LIDAR (EVI-2, selected in 2014)

GEDI will use a laser-based system to study a range of climates, including the observation of the forest canopy structure over the tropics, and the tundra in high northern latitudes. These data will help scientists better understand the changes in natural carbon storage within the carbon cycle from both human-influenced activities and natural climate variations. The instrument will be the first to systematically probe the depths of the forests from space by using a lidar instrument from the ISS and will provide a unique 3D view of Earth's forests and provide information about their role in the carbon cycle. The GSFC will build and manage the instrument.

The ISS will host GEDI. The lidar instrument will be the first to systematically probe the depths of the forests from space and will provide a unique three-dimensional (3D) view of Earth's forests and provide information about their role in the carbon cycle.

Earth Venture Management

The Earth Venture Management provides for the development of AO solicitations and the Technical, Management, and Cost (TMC) evaluations of proposals received in response to the AO solicitations. Additionally, the management supports Common Instrument Interface activities to identify a common set of earth science instrument-to-spacecraft interface guidelines that will improve the likelihood that these instruments can take advantage of future hosted payload opportunities.

As funding and opportunities permit, NASA supports a small number of technology studies, in an effort to prepare these technologies to compete in future Earth Venture solicitations. In 2015, NASA selected two technology demonstration efforts from EVI-2:

- Green OAWL (GrOAWL): The GrOAWL Demonstrator effort is reducing risk for a potential future ATHENA-OAWL Doppler Wind Lidar mission by providing validated airborne wind profiles measured with a 532-nanometer version of the Optical Autocovariance Wind Lidar instrument. The University of Colorado managed this work, and Ball Aerospace Corporation built the GrOAWL instrument. NASA conducted flight tests in FY 2016 and completed data analysis in FY 2018.
- Temporal Experiment for Storms and Tropical Systems-Demonstrator (TEMPEST-D): As a technology demonstration effort, a TEMPEST-Demonstrator is reducing the risk for a potential future TEMPEST mission that will provide the first global observations of the time evolution of precipitation. TEMPEST-D provides for a single six-unit CubeSat with the required set of five millimeter-wave frequencies from 89 to 183 GHz. With launch scheduled for the third quarter of FY 2018, TEMPEST-D will validate existing airborne and satellite-based millimeter-wave radiometer data through geolocation, calibration, and intercalibration of brightness temperatures with the Global Precipitation Measurement Microwave Imager (GMI) and other available satellite radiometers. Colorado State University is leading this work, and the Jet Propulsion Laboratory (JPL) is building the 5-frequency radiometer instrument.

Earth Venture Suborbital-2 (EVS-2; selected in 2014)

- EVS-2 investigations include:
- ATom explores the impact of human-produced air pollution on certain gases that trap heat. Airborne instruments will look at how various air pollutants affect atmospheric chemistry (including methane and ozone).
- NAAMES seeks to improve predictions of how ocean ecosystems would change with temperature increases. The mission will study the annual life cycle of phytoplankton, and the impact small

airborne particles (composed of material derived from marine organisms) have on climate in the North Atlantic.

- ACT-America quantifies the sources of regional carbon dioxide, methane and other gases, and documents how weather systems transport these gases in the atmosphere.
- ORACLES investigates how smoke particles from massive biomass burning in Africa influences cloud cover over the Atlantic. Particles from this seasonal burning interact with permanent stratocumulus “climate radiators,” which are critical to the regional and global climate system.
- OMG project studies the role of warmer, saltier Atlantic Ocean subsurface waters in Greenland glacier melting. The study will help pave the way for improved estimates of future sea level rise by observing changes in glacier melting where ice contacts seawater.
- The CORAL (selected in FY 2015) investigation will analyze the status of coral reefs and predict their future. It will provide the most extensive picture to date of the condition of a large portion of the world’s coral reefs.

Multi-Angle Imager for Aerosols (MAIA) (EVI-3, Selected in 2016)

MAIA will use a multi-angle imager to assess linkages between different airborne particulate matter types and human health (including adverse birth outcomes, cardiovascular and respiratory disease, and premature death). This project will retrieve concentrations of fine and coarse particles, sulfate, nitrate, organic and black carbon, and mineral dust particles in major urban areas around the globe on a one-kilometer grid.

A low-Earth orbit commercial satellite will host the MAIA instrument. The MAIA instrument uses multi-angle and multispectral radiometry and polarimetry to retrieve aerosol optical depths of different particle types. The MAIA science team will correlate the data with birth, death, and hospital records and will use established epidemiological methodologies to correlate the exposure to particulate matter with adverse health outcomes.

Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) (EVI-3, Selected in 2016)

TROPICS will make measurements over the tropical latitudes to observe the thermodynamics and precipitation structures of Tropical Cyclones (TCs) over much of the storm systems’ lifecycles. The measurements will provide nearly all-weather observations of 3D temperature and humidity, as well as, cloud ice, precipitation horizontal structure and instantaneous surface rain rates. These measurements and the increased temporal resolution, provided by the CubeSat constellation, will enable better understanding of the TC lifecycles and the environmental factors that affect the intensification of TCs.

TROPICS six CubeSats will each have a cross-track scanning multiband passive microwave radiometer in a 1U payload (1U, a CubeSat unit, is roughly equivalent to a 4-inch cubic box, or 10x10x10 cubic centimeters).

Geostationary Carbon Cycle Observatory (GeoCarb) (EVM-2, Selected in 2016)

GeoCarb will advance our understanding of Earth's natural exchanges of carbon between the land, atmosphere, and ocean. The primary goals of the mission are to monitor plant health, vegetation stress throughout the Americas, and to probe, in unprecedented detail, the natural sources, sinks, and exchange processes that control carbon dioxide, carbon monoxide, and methane in the atmosphere.

The PI-led mission will launch on a commercial communications satellite to make observations over the Americas from an orbit of approximately 22,000 miles (35,400 kilometers) above the equator. GeoCarb will measure daily the total concentration of carbon dioxide, methane, and carbon monoxide in the atmosphere with a horizontal ground resolution of 3 to 6 miles (5 to 10 kilometers). GeoCarb also will measure solar-induced fluorescence, a signal related directly to changes in vegetation photosynthesis and plant stress.

Program Schedule

Date	Significant Event
Dec 2017	EVS-3 (suborbital) solicitation released
Apr 2018	EVI-5 (instrument) solicitation released
Jun 2018	ECOSTRESS Instrument Delivery to ISS
2019	GEDI Instrument Delivery to ISS
2019	EVM-3 (mission) solicitation released
2019	TEMPO delivery to host spacecraft
2019	EVI-6 (instrument) solicitation released
2021	TEMPO launch readiness
2021	EVS-4 (suborbital) solicitation release
2021	MAIA launch readiness
2021	EVI-7 (instrument) solicitation released
2022	GeoCarb launch readiness
2022	EVI-8 (instrument) solicitation released
2023	EVM-4 (mission) solicitation released

VENTURE CLASS MISSIONS

Program Management & Commitments

The Earth System Science Pathfinder (ESSP) program at Langley Research Center (LaRC) manages the Venture Class projects. The "Provider" in the following table lists the PI institution for each project.

Program Element	Provider
EVS-2: ATom	Provider: Harvard College Lead Center: ARC Performing Center(s): LaRC, ARC, GSFC, AFRC, JPL Cost Share Partner(s): NOAA
EVS-2: NAAMES	Provider: Oregon State University Lead Center: LaRC Performing Center(s): LaRC, GSFC, ARC Cost Share Partner(s): N/A
EVS-2: ACT-America	Provider: Pennsylvania State University Lead Center: LaRC Performing Center(s): LaRC, GSFC, JPL Cost Share Partner(s): N/A
EVS-2: ORACLES	Provider: ARC Lead Center: ARC Performing Center(s): ARC, LaRC, GSFC, AFRC, JPL Cost Share Partner(s): University of Namibia
EVS-2: OMG	Provider: JPL Lead Center: JPL Performing Center(s): JPL, GSFC, AFRC, JSC Cost Share Partner(s): Danish National Space Institute, Stockholm University
EVS-2: CORAL	Provider: Bermuda Institute of Ocean Sciences Lead Center: JPL Performing Center(s): JPL, AFRC Cost Share Partner(s): N/A
EVM-1: CYGNSS	Provider: University of Michigan Lead Center: LaRC Performing Center(s): N/A Cost Share Partner(s): N/A
EVM-2: GeoCarb	Provider: University of Oklahoma Lead Center: LaRC Performing Center(s): ARC, GSFC, JPL Cost Share Partner(s): N/A

VENTURE CLASS MISSIONS

Program Element	Provider
EVI-1: TEMPO	Provider: Smithsonian Astrophysical Observatory Lead Center: LaRC Performing Center(s): LaRC, GSFC Cost Share Partner(s): N/A
EVI-2: ECOSTRESS	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): USDA
EVI-2: GEDI	Provider: University of Maryland Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
EVI-3: TROPICS	Provider: MIT Lincoln Laboratory Lead Center: LaRC Performing Center(s): GSFC Cost Share Partner(s): N/A
EVI-3: MAIA	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A

Acquisition Strategy

NASA will issue Venture Class solicitations at intervals of every four years for EVS and EVM, and every 18 months for EVI. NASA will award all Venture Class funds through full and open competition.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
CYGNSS: project management, development, integration and mission operations	Southwest Research Institute	San Antonio, TX
TEMPO: development of instrument (ultraviolet-visible spectrometer)	Ball Aerospace & Technologies Corp.	Boulder, CO
GeoCarb: project management, development, integration and mission operations	University of Oklahoma	Norman, OK

VENTURE CLASS MISSIONS

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Feb 2017	GEDI CDR	Successful	FY 2019 Q2
Performance	SRB	Mar 2017	MAIA SRR/IDR	Successful	FY 2018 Q2
Performance	SRB	May 2017	TROPICS SRR	Successful	Jun 2017
Performance	SRB	Sep 2017	GeoCarb SRR/MDR	Successful	FY 2018 Q3
Performance	SRB	FY 2018 Q1	TROPICS PDR	TBD	FY 2018 Q2
Performance	SRB	FY 2018 Q2	ECOSTRESS ORR	TBD	FY 2018 Q3
Performance	SRB	FY 2018 Q3	MAIA PDR	TBD	FY 2018 Q3
Performance	SRB	FY 2018 Q3	GeoCarb PDR	TBD	FY 2019 Q1
Performance	SRB	FY 2019 Q1	GeoCarb CDR	TBD	FY 2023 Q2
Performance	SRB	FY 2019 Q1	MAIA CDR	TBD	FY 2020 Q1
Performance	SRB	FY 2019 Q2	GEDI ORR	TBD	N/A
Performance	SRB	FY 2019 Q4	TROPICS ORR	TBD	N/A
Performance	SRB	FY 2020 Q2	TEMPO ORR	TBD	N/A
Performance	SRB	FY 2021 Q4	MAIA ORR	TBD	N/A
Performance	SRB	FY 2023 Q2	GeoCarb ORR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	FY 2020	Notional FY 2021	FY 2022	FY 2023
ESSP Missions Research	11.4	--	**12.5**	16.0	17.5	19.7	23.5
Orbiting Carbon Observatory-3	18.0	--	**0.3**	0.3	0.3	0.3	0.3
Small Satellite Constellation Initiative	0.0	--	**25.0**	25.0	25.0	25.0	25.0
OCO-2	10.4	--	**11.4**	11.0	10.2	10.4	10.7
Aquarius	2.8	--	**0.0**	0.0	0.0	0.0	0.0
GRACE	5.2	--	**2.4**	0.0	0.0	0.0	0.0
CloudSat	7.9	--	**9.4**	9.6	9.9	10.1	10.4
Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)	6.7	--	**6.5**	6.6	6.2	4.8	4.4
Total Budget	**62.3**	**--**	**67.5**	**68.6**	**69.0**	**70.3**	**74.3**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

ESSP Other Missions and Data Analysis projects include operating missions and mission-specific research. These innovative missions will enhance understanding of the current state of the Earth system and enable continual improvement in the prediction of future changes.

Mission Planning and Other Projects

ESSP MISSIONS RESEARCH

ESSP Missions Research provides funds for the science teams supporting ESSP operating missions. The science teams are comprised of competitively selected individual investigators who analyze data from the missions to address relevant science questions.

Recent Achievements

A recent study suggests that Saharan dust modifies Atlantic marine stratocumulus clouds such that they cool the planet. Researchers find a strong seasonal variation, with the aerosol–cloud radiative effect switching from significantly negative during the boreal summer to weakly positive during boreal winter. This study used observational data for the time between 2004 and 2012, mainly from CALIPSO and from the Monitoring Atmospheric Composition and Climate reanalysis dataset.

Aerosol indirect effects have uncertain, but potentially large, impacts on the Arctic energy budget. Researchers have reduced uncertainty in estimates of current-day Arctic net aerosol indirect effects. They achieved this by better constraining various characteristics of optically thin, liquid-containing clouds in clean, average, and aerosol-impacted conditions using a combination of CALIPSO and CloudSat data and

OTHER MISSIONS AND DATA ANALYSIS

model output. The work provides a foundation for how future observational studies can evaluate model estimates of the aerosol indirect effect. In a recent publication investigators explained how the more than 10 years of observations jointly collected by CloudSat and CALIPSO satellites clearly demonstrate the fundamental importance of the vertical structure of clouds and aerosol particles. These satellites increased the understanding of the influences of larger scale atmospheric circulation on aerosol distributions, the hydrological cycle, cloud-scale physics and the formation of major storm systems.

High-resolution satellite data from OCO-2 are revealing the subtle ways that carbon links everything on Earth -- the ocean, land, atmosphere, terrestrial ecosystems, and human activities. Using the first 2 1/2 years of OCO-2 data, scientists published a special collection of five papers in October 2017 in the journal *Science* that demonstrates the breadth of this research. In addition to showing how drought and heat in tropical forests affected global carbon dioxide levels during the 2015 - 2016 El Niño, other results from these papers focus on ocean carbon release and absorption, urban emissions, and a new way to study photosynthesis. The last paper from the special collection gives an overview of the state of OCO-2 science.

Data from Mauna Loa Observatory and OCO-2 show that the 2015 - 2016 El Niño event coincides with the largest annual increase in carbon dioxide (about 3 ppm) since measurements began in the 1950s, even though human emissions were roughly the same as in the preceding year. A recent study shows that tropical continents were the primary source of that record increase of carbon dioxide, with about 2.5 gigatons higher carbon emissions as compared to 2011, which is considered a normal year. In the 2015 - 2016 El Niño period, tropical South America, including the Amazon rainforest, was the driest recorded in the last 30 years. Trees went dormant or died, reducing photosynthesis and leaving more carbon in the atmosphere. African rainforests endured hotter-than-normal temperatures. Decomposition of dead trees increased, releasing more carbon to the atmosphere. In Southeast Asia, drought increased the size and duration of peat and forest fires, releasing more carbon to the atmosphere.

Researchers studied the total column atmospheric CO2 measurements from the OCO-2 instrument using observations over the eastern equatorial Pacific. Results show a significant reduction of CO2 due to reduced outgassing from the ocean at the onset of the 2015 - 2016 El Niño event, followed by an increase in CO2 due to enhanced respiration and biomass burning in South America.

Using high spatial resolution OCO-2 images, scientists investigated localized sources and sinks of CO2 associated with urban centers and volcanoes. On a single orbit, OCO-2 measurements enabled the differentiation of local sources approximately about six parts per million by volume (ppmv) over Los Angeles, USA. This means that the measurements can distinguish different sources of carbon of approximately six ppmv. Overall, on an average global scale, results showed researchers could distinguish different sources on the order of one ppmv with OCO-2.

NASA funded scientists used GRACE data to develop and publish a drought severity index (DSI) that monitors terrestrial water storage changes. This index has shown good agreement with existing monthly indices such as the Palmer Drought Severity Index, standardized precipitation and evapotranspiration index, and the normalized difference vegetation index, as well as surface soil moisture estimates, and in-situ groundwater observations. GRACE data and DSI also incorporate the human impacts of groundwater withdrawal. The DSI could be a globally consistent and effective drought-monitoring tool, particularly where sparse ground observations (especially precipitation) limit traditional methods of drought monitoring.

OTHER MISSIONS AND DATA ANALYSIS

Scientists published the first quantification of depleting groundwater embedded in the world's food trade by combining unique global, crop-specific estimates of nonrenewable groundwater abstraction with international food trade data. They found that food trade embedded approximately eleven percent of non-renewable groundwater use for irrigation, of which Pakistan, the United States and India exported two thirds. The scientists used a global hydrological and water resources model to simulate crop water use for 26 irrigated crop types, validated with groundwater data, country statistics, and NASA's GRACE satellite observations.

A recent study quantified the exchange of water between land and ocean (through precipitation, evaporation, and winds) and its impact on calculation of the contribution of hydrologic mass variability on sea level budget estimates. Taking advantage of GRACE measurements, the team estimated that because of climate changes, an additional 3200 Gt (1 Gigatonne = 109 Kilograms) of water has been stored on land since 2002. This net groundwater storage partially offsets water losses from melting ice sheets, glaciers, and groundwater extraction, and thus slowing down the rate of recent sea level rise by about 15 percent.

SMALL SATELLITE CONSTELLATIONS INITIATIVE

The Small Satellite Constellation Initiative focuses on increasing the use and utility of constellations of small satellites to acquire Earth observation data required for Earth system science research. NASA designed the initiative to enable, foster, and encourage spaceflight solutions for Earth science missions that involve the use of multiple, instrumented small satellites flying in various tight or loose formations, to achieve the quality and quantity of data required by the research and applications communities. The project will capitalize on the increasing availability of commercial, low-cost, miniaturized small satellites and instruments to investigate and demonstrate the science capabilities and programmatic robustness of small satellite constellations in comparison with traditional single-mission, multi-instrument satellite observatories.

Potential small satellite constellation activities include on-orbit technology validation and risk reduction for small instruments; fostering commercial launch services dedicated to transporting small payloads into orbit; funding competitive grants for small satellite proposals; and exploring governance models to incentivize Center involvement in purchasing small satellite constellation data products as appropriate.

Recent Achievements

In FY 2016, NASA released an RFI and conducted extensive market research. Five potential commercial suppliers of small satellites constellations data products responded. Of the five, one collected data, one had plans to launch constellations of small satellites and the last three did not have data products to offer or plans to launch constellations of small satellites. The market research activity continued in FY 2017 identifying two new potential suppliers of data products.

NASA will issue a solicitation for small satellite constellation data products in the third quarter of FY 2018. This solicitation aims to acquire and validate one-year worth of small satellite constellation data products, determine its value to the research community, and identify data policies for government use of the commercially acquired data products.

OTHER MISSIONS AND DATA ANALYSIS

Operating Missions

OCO-2

The OCO-2 mission collects hundreds of thousands of precise carbon dioxide measurements across the globe each day from its vantage point in low Earth orbit. With these data, scientists are gaining greater insight into how much carbon dioxide the Earth emits by natural sources and human activities, and the natural processes removing carbon dioxide from the atmosphere. This information may help decision-makers to manage carbon dioxide emissions and reduce the human impact on the environment.

The Orbiting Carbon Observatory-2 (OCO-2) instrument has collected almost 1 million soundings globally each day since September 2014, completed its prime mission in October 2016, and is now in its first extended mission. The 2017 Earth Science Senior Review endorsed the OCO-2 mission for continued operations through 2020, and preliminarily, through 2023.

Recent Achievements

In 2017, NASA released new versions of the OCO-2 data products, with significantly improved scientific quality, and extending useful observations to the highest northern and southern latitudes. This release offers the opportunity for new investigations into the processes governing carbon exchange between the atmosphere and the Southern Ocean and the northern boreal forests.

GRAVITY RECOVERY AND CLIMATE EXPERIMENT (GRACE)

Gravity Recovery and Climate Experiment (GRACE) measures minute changes in Earth’s gravity field by measuring micron-scale variations in the separation between the two spacecraft that fly in formation 220 kilometers apart in low Earth orbit. Local changes in Earth’s mass cause the variations in gravitational pull. GRACE demonstrated a new paradigm of observations that utilizes ultra-small variations of Earth’s gravity field, as small as one-billionth the surface force of gravity. With this capability, GRACE was the first mission to provide a comprehensive measurement of the monthly change in the ice sheets and major glaciers. GRACE provided significant new information on changes in water resources within river basins and aquifers worldwide, and measured the effects of major earthquakes around the world. NASA developed the twin GRACE satellites in collaboration with German Aerospace Center (DLR).

The 2015 Earth Science senior review endorsed the GRACE mission for continued operations through 2017 and preliminarily through 2019, or until re-entry.

Recent Achievements

In October 2017, the Gravity Recovery and Climate Experiment (GRACE) mission ended science operations due to a failed battery. The mission was in operations for 15 years, greatly exceeding its planned 5-year prime mission. FY 2019 – FY 2020 funding will support final data processing and closeout activities.

OTHER MISSIONS AND DATA ANALYSIS

CLOUDSAT

CloudSat measures cloud characteristics to increase understanding of the role of clouds in Earth's radiation budget. This mission provides estimates of the percentage of Earth's clouds that produce rain, provides vertically-resolved estimates of how much water and ice are in Earth's clouds, and estimates how efficiently the atmosphere produces rain from clouds. CloudSat collects information about the vertical structure of clouds and aerosols that other Earth-observing satellites do not collect. These data improves models and provide a better understanding of the human impact on the atmosphere.

CloudSat launched in 2006 and is currently in extended operations. The 2017 Earth Science senior review endorsed the CloudSat mission for continued operations through 2020, and preliminarily, through 2023.

Recent Achievements

The CloudSat data record continues to reveal new and unique information about cloud and precipitation processes around the Earth. In 2017, CloudSat began the release of its improved Version 5 data products used to improve cloud and precipitation processes in weather forecasting models. Researchers have used CloudSat data to evaluate the accuracy of weather satellite in regions with strong horizontal and vertical wind shear, which create safety concerns for the aviation industry. The CloudSat project continues to collaborate with the Global Precipitation Measurement (GPM) mission to produce routinely a data product of coincident (at the same time) satellite overpasses to improve estimates of rain and snow around the globe.

CLOUD-AEROSOL LIDAR AND INFRARED PATHFINDER SATELLITE OBSERVATION (CALIPSO)

The CALIPSO mission provides the first comprehensive three-dimensional measurement record of aerosols, helping to better understand how aerosols form, evolve, and are transported over the globe. The mission provides data on the vertical structure of clouds, the geographic and vertical distribution of aerosols, and detects sub-visible clouds in the upper troposphere. CALIPSO also indirectly estimates the contribution of clouds and aerosols to atmospheric temperature.

Launched in 2006, CALIPSO is currently in extended operations. The 2017 Earth Science senior review endorsed the CALIPSO mission for continued operations through 2020, and preliminarily, through 2023.

Recent Achievements

In FY 2017, the CALIPSO mission produced and released a new version of the Infrared Imaging Radiometer observational record with improved calibration that will provide more accurate retrievals of cirrus cloud properties. The mission also developed new data algorithms that will enable studies on sulfuric acid aerosols in the stratosphere and understand the three-dimensional distribution of clouds over the globe. The mission further supported the calibration and validation of the Cloud-Aerosol Transport System lidar on the International Space Station, field campaigns investigating phytoplankton ecosystems in the North Atlantic Ocean, the impact of smoke particles on clouds off the coast of southwest Africa, and how cirrus clouds warm and cool the atmosphere.

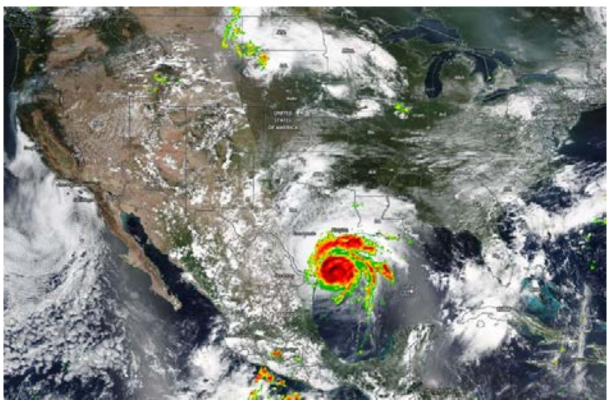
EARTH SCIENCE MULTI-MISSION OPERATIONS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	204.9	--	196.9	208.7	225.0	231.6	237.1

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



Hurricane Harvey made landfall on the Texas Coast on 25 August 2017 then stalled, dumping up to 50 inches of rain in some areas. This image shows Rain Rate (Ascending) from GMI/GPM captured around 11:50 UTC (6:50AM CDT) on 25 August 2017, where darker reds indicate higher rainfall rates, overlaid on a reflectance image from VIIRS/Suomi NPP captured around 18:55 UTC (1:55 PM CDT). Image created by NASA Worldview. https://worldview.earthdata.nasa.gov

The Earth Science Multi-Mission Operations (MMO) program acquires, processes, preserves, and distributes observational data from operating spacecraft to support Earth Science research focus areas. The MMO program primarily accomplishes this via the Earth Observing System Data and Information System (EOSDIS), which has been in operations since 1994. The EOSDIS team creates earth science data products from satellite, airborne and field campaign data that grow at the rate of up to 16 terabytes per day.

NASA archives Earth Science information at Distributed Active Archive Centers (DAACs) located across the United States. The DAACs specialize by science discipline, and make their data available to researchers and industries around the world.

The MMO program supports the data archive and distribution for upcoming Earth Science missions. It recently began acquiring and distributing data from the European Space Agency’s Sentinel missions under a bilateral agreement with the European Union. EOSDIS data centers also support Earth Ventures Suborbital campaigns. In response to the 2007 National Academies decadal survey a system plan for 2017 and beyond will take into account evolutionary needs for new missions in development, including ICESat-2, NISAR, and SWOT. These investments will enable the system to keep technologically current, and incorporate new research data and services.

Advancing Collaborative Connections for Earth System Science (ACCESS) supports the evolution of EOSDIS by investing in technology to enhance the analysis, delivery, and preservation of Earth science. NASA solicits proposals in this competitive program element every two years. The intent is to identify and develop promising technology prototypes into operational tools to infuse into the EOSDIS.

EARTH SCIENCE MULTI-MISSION OPERATIONS

The MMO project guides a broad effort to leverage the Federal Government's extensive, freely available Earth science data resources to stimulate innovation and private-sector entrepreneurship. This effort works closely with many federal agencies to make Earth science datasets and resources discoverable through https://www.data.gov.

For more information, go to http://science.nasa.gov/earth-science/earth-science-data.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

The EOSDIS archives grew to over 24 Petabytes. EOSDIS distributed over 1.3 billion data products to 2.9 million users around the world. The 2017 EOSDIS American Customer Satisfaction Index score was 78 – considered in the "very good" range. EOSDIS provided data stewardship to over 11,000 unique data products from more than 100 instruments, available to users worldwide.

EOSDIS DAACs supported Cyclone Global Navigation Satellite System (CYGNSS) and several instruments deployed on the International Space Station (ISS), including Land Information System (LIS) and Stratospheric Aerosol Gas Experiment (SAGE-III). The project has also prepared for the upcoming deployment of Total Sand Spectral Solar Irradiance (TSIS-1) and Tropospheric Emissions: Monitoring Pollution (TEMPO) missions.

Studies continued to evaluate the cost, technical performance, and security implications of utilizing commercial cloud computing technology for core EOSDIS functions. Early results from the evaluations demonstrated commercial cloud environments are viable for operation of science systems. One benefit of the prototype activities is the EOSDIS search engine seamlessly migrated into a commercial cloud computing environment, increasing performance and reducing costs with no impact to users. The EOSDIS search engine provides the ability to search over 33,000 data collections with 97 percent of queries completing in less than one second.

EOSDIS continued expanding the NASA Sentinel Gateway to support data from multiple European Space Agency (ESA) Sentinel missions. It is acquiring data from Sentinel-1A, 1-B and 3-A. The gateway transfers data to the appropriate DAACs for archive and distribution to the NASA science user community.

EOSDIS released open source software for the Earthdata Search Client (EDSC), Common Metadata Repository (CMR), Global Image Browse Services (GIBS), and Worldview.

Selected MEaSURES accomplishments in FY 2017 include:

Produced a global, 25+ yearlong consistent time series of sea level, both in along track form and uniformly gridded. Consistent processing of altimetry data from 1993 to 2016 of all altimetry satellites, measuring sea surface height every 10 days, developed this climate record.

The Greenland Ice Mapping Project developed a consistent, multi-sensor monthly-to-decadal scale set of Earth Science Data Records that capture 21st century glacier change (2000–present) using optical and radar data. Greenland Ice Mapping Project products have documented a large degree of glacier variability, while helping to establish that there is less potential for run-away ice loss than was initially feared when observations of rapid change were first made.

The Freeze/Thaw Earth System Data Record quantifies daily landscape freeze/thaw state dynamics over all global land areas where seasonal frozen temperatures are a significant constraint to ecosystem processes and land surface water mobility. The data set encompasses all land areas affected by seasonal frozen temperatures (~93 million square kilometers) and extends over more than 37 years (1979 to 2016), representing one of the longest satellite environmental data records in existence.

The global Web-Enabled Landsat Data record project generated large area 30-meter Landsat composited mosaics with a monthly and annual reporting frequency for the entire earth's terrestrial surface except Antarctica. The monthly and annual products provide consistent 30-meter data. Researchers use the data to derive land cover as well as geophysical and biophysical products.

WORK IN PROGRESS IN FY 2018

The MMO project is supporting ICESat-2, GRACE-FO, and ECOSTRESS with increased capacity and new capabilities at the National Snow & Ice Data Center, Physical Oceanography, and Alaska Satellite Facility DAACs. MMO is also implementing and testing capabilities required for archive and distribution of the data from the NISAR and SWOT missions.

To address anticipated growth in both the EOSDIS data ingest rate as well as the overall archive volume, EOSDIS is continuing to examine the effectiveness of using a commercial cloud to ingest, archive, process, distribute, and manage the anticipated large volumes of new mission data. EOSDIS is developing a lightweight cloud-native framework (Cumulus) for data ingest, archive, distribution, and management within a NASA security compliant commercial cloud environment.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

MMO will expand its capabilities to support data from new missions, including GEDI and MAIA. MMO will deploy Cumulus into a commercial cloud environment for management and distribution of high-value data sets from MODIS in parallel to current DAAC systems. Cumulus will also support ground system interface testing for the high volume NISAR and SWOT missions.

Program Elements

EARTH SCIENCE MULTI-MISSION OPERATIONS

This project funds the evolution of EOSDIS elements, aimed at improving the efficiency and effectiveness of EOSDIS while reducing the cost. It also supports the twelve nationwide DAAC installations that collect, disseminate, and archive earth science data. Each DAAC focuses on a specific Earth system science discipline and provides users with data products, services, and data-handling tools unique to that specialty.

- The Alaska Synthetic Aperture Radar Facility collects data and information on sea ice, polar processes, and geophysics;
- The GSFC Earth Sciences Data and Information Services Center collects information on atmospheric composition, atmospheric dynamics, global precipitation, ocean biology, ocean dynamics, and solar irradiance;
- The LaRC DAAC collects data on Earth's radiation budget, clouds, aerosols, and atmospheric chemistry;
- The Land Processes DAAC collects land processes and land cover change data;
- The National Snow and Ice Data Center collects snow and ice data, as well as environmental information about the cryosphere and climate;
- The Oak Ridge National Laboratory DAAC collects data on biogeochemical dynamics and ecological data for studying environmental processes;
- The Physical Oceanography DAAC collects information on oceanic processes and air-sea interactions;
- The Socioeconomic Data and Applications Center collects information on human dimensions including population, sustainability, multilateral environmental agreements, natural hazards, and poverty;
- The Crustal Dynamics Data Center collects information focused on solid earth and geodesy data;
- The Ocean Biology Progressing Group produces and distributes ocean biology and biogeochemistry products;
- The Global Hydrology Research Center provides hydrological cycle and severe weather research data and information; and
- The Level 1 and Atmosphere Data Center provides a comprehensive suite of Moderate Resolution Imaging Spectroradiometer (MODIS) and Visible Infrared Imaging Radiometer Suite (VIIRS) atmospheric products.

EARTH OBSERVING SYSTEM DATA AND INFORMATION SYSTEM (EOSDIS)

The EOSDIS project provides science data to a wide community of users, including NASA, Federal agencies, international partners, academia, and the public. EOSDIS provides users with the services and tools they need in order to use NASA's earth science data in research and creation of models. EOSDIS archives and distributes data through standardized science data products, using algorithms and software developed by Earth Science investigators.

The EOSDIS project also funds research opportunities related to EOSDIS. ACCESS projects increase the interconnectedness and reuse of key information-technology software and services in use across the spectrum of earth science investigations. ACCESS also supports the deployment of data and information systems and services that enable the freer movement of data and information. ACCESS researchers develop needed tools and services to aid in measurable improvements to Earth science data access and usability.

MAKING EARTH SYSTEM DATA RECORDS FOR USE IN RESEARCH ENVIRONMENTS (MEASURES)

The overall objective of MEaSUREs is to provide Earth science higher-level data products and services driven by NASA's Earth science goals.

EARTH SCIENCE MULTI-MISSION OPERATIONS

These data products, Earth Science Data Records, are critical for: understanding Earth System processes; assessing variability, long-term trends, and changes in the Earth System; and providing input and validation means to modeling efforts.

MEaSUREs emphasizes linking together multiple satellites into a constellation, developing the means of utilizing a multitude of data sources to form a coherent time series, and facilitating the use of NASA's extensive data in the development of comprehensive Earth system models. In addition, MEaSUREs projects include infusion or deployment of applicable science tools that contribute to data product quality improvement, consistency, merging or fusion, or understanding.

Program Schedule

The MMO program solicits research opportunities approximately every two years for ACCESS and every five years for MEaSUREs.

Date	Significant Event
Q1 FY 2018	ROSES ACCESS Solicitation Released
Q1 FY 2020	ROSES ACCESS Solicitation Released
Q2 FY 2022	ROSES MEaSUREs Solicitation Released

Program Management & Commitments

The Earth Systematic Missions (ESM) program at GSFC provides program management for the MMO program.

Program Element	Provider
EOSDIS core system, and Evolution of EOSDIS upgrades	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
DAACs	Provider: Various Lead Center: GSFC Performing Center(s): GSFC, LaRC, Marshall Space Flight Center (MSFC), JPL Cost Share Partner(s): N/A

Acquisition Strategy

Research opportunities related to EOSDIS and MEaSUREs are available through NASA's ROSES announcements.

EARTH SCIENCE MULTI-MISSION OPERATIONS

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
EOSDIS Evolution & Development	Raytheon	Riverdale, MD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	American Customer Satisfaction Index	2017	Survey current EOSDIS users to assess current status and improve future services	Successful	2018 annually

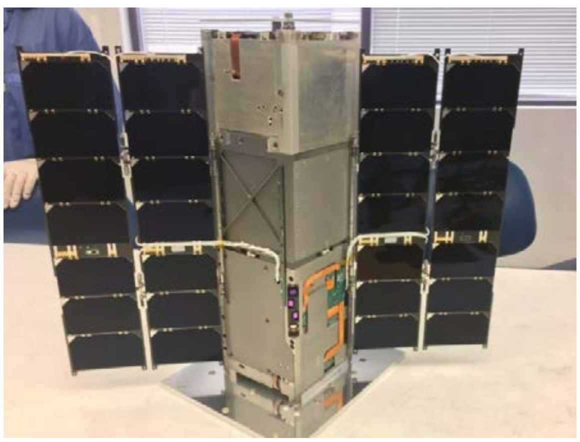
EARTH SCIENCE TECHNOLOGY

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	62.9	--	59.7	61.6	64.2	67.8	69.6

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



Developed at Johns Hopkins Applied Physics Laboratory, the Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN) CubeSat launched into low-Earth orbit on Nov. 11, 2016. Designed to measure the amount of reflected solar and thermal energy emitted into space, RAVAN employs two technologies that have never before been used on an orbiting spacecraft: carbon nanotubes that absorb outbound radiation and a gallium phase change blackbody for calibration. RAVAN remains healthy and continues to collect data. (Image Credit: William Swartz / JHU-APL)

Advanced technology plays a major role in enabling Earth science research and applications. The Earth Science Technology Program (ESTP) enables previously infeasible science investigations; improves existing measurement capabilities; and reduces the cost, risk, and/or development times for earth science instruments and information systems.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

The ESTP worked on 141 active projects in FY 2017. For projects eligible to do so, 57 percent advanced at least one Technology Readiness Level (TRL) during the fiscal year. In addition, several projects, past and present, have been infused into science measurements, airborne campaigns, data systems, or other follow-on activities during the year. For example, the GeoCARB mission will utilize Tropospheric Infrared Mapping Spectrometers for atmospheric CO profile measurements developed under the 2004 Instrument Incubator Program.

The program awarded 17 proposals through the 2016 Instrument Incubator Program element solicitation and work commenced in FY 2017. The program released the Advanced Information Systems Technology (AIST) program element solicitation and selected 21 proposals with work to commence in FY 2018.

The In-Space Validation of Earth Science Technologies (InVEST) program element launched two technology demonstrations in FY 2017. The first, launched in November 2016, was the Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN) CubeSat. RAVAN demonstrated a small, accurate radiometer to measure the strength of the Earth's outgoing radiation across the entire spectrum of energy, from the ultraviolet to the far infrared. The second, IceCube, launched as well, and subsequently deployed from, the International Space Station in April 2017. IceCube has demonstrated a new submillimeter wave radiometer technology and took, for the first time, global measurements of cloud ice at 883 GHz.

WORK IN PROGRESS IN FY 2018

In January 2018 the National Research Council of the National Academies released new strategic direction in the form of the latest Decadal Survey for Earth Science and Applications from Space. As was the case with the 2007 decadal survey, NASA expects that investments made through the ESTP will be available immediately to address the measurement goals outlined in the updated version.

New solicitations are planned for FY 2018 and beyond that will aid in fully realizing the updated direction. The program made 12 selections under the Advanced Component Technologies (ACT) program element in early FY 2018. The In-Space Validation of Earth Science Technologies (InVEST) program element and the Advanced Information Systems Technology (AIST) program element will release solicitations.

The program also plans technology demonstration launches in FY 2018 within the InVEST program element: three launches planned during the second quarter of FY 2018 include the HyperAngular Rainbow Polarimeter (HARP), RainCube, and the CubeSat Radiometer Radio Frequency Interference Technology (CubeRRT).

KEY ACHIEVEMENTS PLANNED FOR FY 2019

The InVEST program element plans to launch the Microwave Radiometer Technology Acceleration (MiRaTA) 3-unit CubeSat in November 2018. The program anticipates the selection of awards under the AIST and InVEST program elements as well as the release of a solicitation by the IIP program element. The new awards under IIP will be selected and commence work in FY 2020. The InVEST program element also plans the launch of the Compact Infrared Radiometer in Space (CIRiS) CubeSat in early FY 2019.

EARTH SCIENCE TECHNOLOGY

Program Elements

ADVANCED TECHNOLOGY INITIATIVES (ATI)

This project enables development of critical component and subsystem technologies for instruments and platforms, mostly in support of the Earth Science decadal survey. Current awards focus on areas such as space-qualified laser transmitters, passive optical technologies, and microwave and calibration technologies. Other awards support measurements of solar radiance, ozone, aerosols, and atmospheric gas columns for air quality and ocean color for coastal ecosystem health and climate emissions.

The InVEST program element selects new technologies to validate in space prior to use in a science mission. This is necessary because the space environment imposes stringent conditions on components and systems, some of which we cannot test on the ground or in airborne systems. Validation of earth science technologies in space will further reduce the risk of new technologies in future Earth Science missions.

INSTRUMENT INCUBATOR

This project develops instrument and measurement techniques at the system level, including laboratory breadboards and operational prototypes that often lead to ground or airborne demonstrations. NASA currently funds 17 Instrument Incubator efforts. These instrument prototypes support several measurements such as carbon dioxide, carbon monoxide, ocean color, and solar spectrum from ultraviolet to infrared for earth science. Instrument Incubator supports the development of instrument design and prototyping through laboratory and/or airborne demonstrations for innovative measurement techniques that have the highest potential to meet the measurement capability requirements of the NASA earth science community in both the optical and the microwave spectrum.

ADVANCED INFORMATION SYSTEMS TECHNOLOGY (AIST)

This project develops end-to-end information technologies that enable new Earth observation measurements and information products. The technologies help process, archive, and access, visualize, communicate, and understand science data. Currently, AIST activities focus on four areas needed to support future earth science measurements:

- Concept Development of Improved Sensor Measurements, which includes tools to help assess various types of measurements and how to make them, including technologies that aid in the design and analysis of quantitative observations;
- Data Acquisition and Management, which refers to the collection and management of high-volume and/or high-rate data and supports the building and operation of infrastructures that are necessary for sensor data acquisition;
- Data Product Generation, which is the creation of interdisciplinary products that aggregate observational data, thus improving the scientific value of the data at reduced costs; and
- Exploitation of Data for Earth Science and Applications, which focuses on the transformation of data products into actionable information and includes modeling and visualization tools, as well as collaborative environments. In general, projects aim to advance the discovery, access, and use of sensor data and model output within the Earth Science community.

EARTH SCIENCE TECHNOLOGY

Program Schedule

Date	Significant Event
Q2 FY 2017	ROSES-2017 solicitation
Q1 FY 2018	ROSES-2017 selection no earlier than six months of receipt of proposals
Q2 FY 2018	ROSES-2018 solicitation
Q1 FY 2019	ROSES-2018 selection no earlier than six months of receipt of proposals
Q2 FY 2019	ROSES-2019 solicitation
Q1 FY 2020	ROSES-2019 selection no earlier than six months of receipt of proposals
Q2 FY 2020	ROSES-2020 solicitation
Q1 FY 2021	ROSES-2020 selection no earlier than six months of receipt of proposals
Q2 FY 2021	ROSES-2021 solicitation

Program Management & Commitments

Program Element	Provider
Instrument Incubator	Provider: Various Lead Center: HQ Performing Center(s): GSFC, JPL, LaRC, ARC, AFRC Cost Share Partner(s): N/A
Advanced Information Systems	Provider: Various Lead Center: HQ Performing Center(s): GSFC, JPL, LaRC, MSFC, ARC, GRC Cost Share Partner(s): N/A
Advanced Technology Initiatives	Provider: Various Lead Center: HQ Performing Center(s): GSFC, JPL, LaRC Cost Share Partner(s): N/A

Acquisition Strategy

NASA primarily procures tasks through full and open competition, such as through the ROSES announcements. The solicitation of technology investments is competitive and selected from NASA Centers, industry, and academia.

MAJOR CONTRACTS/AWARDS

None.

EARTH SCIENCE TECHNOLOGY

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Perform-ance	NASA Advisory Council Earth Science Advisory Committee	2012	Review for success in infusion of new technologies and participation of universities in developing the new generation of technologists.	The committee was pleased with the technology program; it recommended focusing on reducing cost in missions and enabling specific measurements.	2018

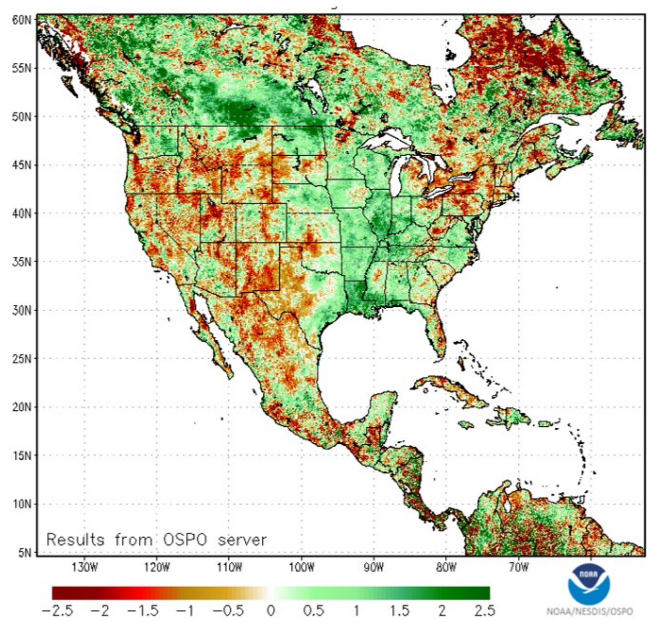
APPLIED SCIENCES

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	FY 2020	Notional FY 2021	FY 2022	FY 2023
Total Budget	**39.4**	**--**	**53.1**	**53.3**	**53.9**	**56.3**	**57.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



The Evaporative Stress Index (ESI) uses NASA satellite data and shows the beginning of drought 2-4 weeks before plant stress shows up in current drought indicators and vegetative indices. The information gives farmers considerable added lead time to offset effects of drought. NOAA adopted this ESI, providing continued operational support and information feeds to stakeholders. The ESI index for July 4, 2016 in the image shows red shading indicating lower than average evapotranspiration rates; green indicates higher rates.

Image Source: NOAA Office of Satellite Products and Operations (NASA/SMD/ESD/Applied Sciences sponsored the project that enabled this capability as well as the transition.)

The NASA Applied Sciences program leverages NASA Earth Science satellite measurements and new scientific knowledge to enable innovative and practical uses by public and private sector organizations. It supports near-term uses of earth science knowledge, discovers and demonstrates new applications, facilitates adoption of applications, and builds capabilities.

Applied Sciences projects improve decision-making activities to help the Nation better manage its resources, improve quality of life, and strengthen the economy. NASA develops Earth science applications in collaboration with end-users in public, private, and academic organizations.

Examples of these applications include:

- Use of wildfire detection data and progression predictions by the U.S. Forest Service to improve determination of fire boundaries and expedite restoration of key ecosystems;
- Inclusion of satellite data in The Centers for Disease Control and Prevention’s Environmental Public Health Tracking Network data for county-level UV exposure information;

- Application of land cover information by the Nature Conservancy to conduct a reverse auction, pay landowners, and increase prime habitat for migrating wild birds;
- Support local governments to use satellite-based land-surface temperature data, emissivity data, and imagery to identify populations most vulnerable to extreme heat and guide service efforts;
- Use of satellite images and data to support companies' fishing operations and support sustainable fisheries; and
- Use of satellite observations of volcanic ash to inform air traffic controllers and the aviation industry for hazards along major airplane routes.

The program supports the sustained use of these products in the decision-making process of user organizations. The program also encourages potential users to envision and anticipate possible applications from upcoming satellite missions and to provide input to mission development teams to increase the societal benefits of NASA missions.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

In FY 2017, the South Dakota Department of Health used information products about the West Nile virus based on Terra's Moderate Resolution Imaging Spectroradiometer (MODIS) instrument, Landsat, and North American Land Data Assimilation System to help establish priorities for mosquito control and disease prevention activities. The U.S. Environmental Protection Agency used Aura's Ozone Monitoring Instrument nitrogen dioxide data in its Air Trends Report, marking the first time the report included satellite data. The National Weather Service used MODIS and the Joint Polar Satellite System Visible Infrared Imaging Radiometer Suite (VIIRS) vegetation indices, Landsat multispectral composites, and other Earth observations to enhance its Storm Damage Assessment Toolkit to help refine tornado, severe thunderstorm, and other damage surveys used by downstream partners. The United Nations Great Apes Survival Partnership expanded it use of a SERVIR-developed database of the world's tropical rainforest biomass, helping guide rainforest preservation and great ape conservation in Africa.

NASA used the vantage point of space to support the response to 106 national and international disasters. These disasters include the response to Hurricanes Harvey, Irma, and Maria in late FY 2017. Information products derived from Suomi-National Polar-orbiting Partnership (NPP), MODIS, Soil Moisture Active Passive (SMAP), Global Precipitation Measurement (GPM), Uninhabited Aerial Vehicle Synthetic Aperture Radar, Japan Aerospace Exploration Agency's (JAXA) Advanced Land Observing Satellite, Italian Space Agency's Constellation of small Satellites for the Mediterranean basin Observation, Copernicus/Sentinels, and other sources assisted the National Guard, FEMA, State officials, and others in disaster response efforts, such as the characterization of flood extent, power outages, and impacts to areas of critical infrastructure. Early in FY 2017, NASA supported the response to Hurricane Matthew flooding. Drawing on information from Suomi NPP, SMAP, Land Information System, MODIS, and GPM, the NASA Disasters team helped response agencies identify areas of saturated soils that were prone to flash flooding and generate flood extent maps; information from Suomi NPP and VIIRS also provided crucial insights for detecting which communities had lost power.

APPLIED SCIENCES

The DEVELOP program element an endeavor for young professionals to work with user organizations to apply Earth science data, included 352 people in 73 projects; their work involved 135 unique partner organizations and served efforts in 38 U.S. states. DEVELOP's training endeavor on remote sensing for professionals conducted 18 virtual and in-person trainings, including a first-ever training on synthetic aperture radar that had record attendance. The trainings reached over 4,800 people, including people in all 50 U.S. states, over 125 countries, and hundreds of private sector organizations. The SERVIR program, managed jointly with the U.S. Agency for International Development (USAID), launched a Service Planning Toolkit to support user engagement in Earth observations tool development and to increase tool sustainability.

The Applied Sciences program manages NASA's 2017 International Space Apps Challenge. The focus of the Challenge was on Earth science data, and involved a record 25,000 participants across 69 countries and produced over 2,000 solutions.

The Applied Sciences program selected the independent, nonpartisan organization Resources for the Future to lead a multi-disciplinary organizational consortium. They began work to develop analytic methods for quantifying the socioeconomic benefits from uses of Earth observations. In addition, the program selected the University of Maryland to lead a multi-organization consortium to advance uses of Earth observations by domestic and international organizations to improve food security and agriculture decisions. Applied Sciences solicited, reviewed, and selected projects related to the Group on Earth Observations, leading efforts to advance U.S. interests. The program issued a solicitation for projects addressing applications and decision support for public health and air quality. The Health and Air Quality Applied Sciences Team, selected tiger team projects for focused efforts supporting priority, short-term needs in the health and air quality management communities.

The Applications project also engaged the applications community to expand knowledge about NASA's Earth science missions and in planning for upcoming satellites. The SWOT and NISAR missions held applications workshops; ICESat-2 conducted a focus session on sea level rise and continued work with Early Adopters to apply the data and information; HyspIRI and ECOSTRESS held science and applications meetings; NISAR developed 16 examples of potential applications; PACE created a series of applications concepts; SWOT and ICESat-2 engaged users at a American Water Resources Association symposium; GPM held an agricultural applications workshop; and GRACE created a user guideline to make GRACE data applications easier.

WORK IN PROGRESS IN FY 2018

The Applications project will complete projects and deliver results for nine projects focused on wildland fires in the pre-fire, active-fire, and post-fire phases. The program will deliver results in decision-support projects focused on uses of Earth observations in disasters.

Together with USAID, NASA will announce a new hub serving Amazonia and South America for the SERVIR program element in Capacity Building project. SERVIR will hold its SERVIR Annual Global Exchange event to share applications experiences and examples across its four international hubs. DEVELOP will again sponsor three terms for applications projects. Applied Remote Sensing Training will continue its introductory and advanced level webinars, in-person trainings, and train-the-trainer series; it expects to reach people in all 50 states and over 100 countries.

APPLIED SCIENCES

The Disaster Support project, and the Applications project, will issue solicitations and select proposals for new applications projects related to disasters, health and air quality, and water resources management. The Applications project will also implement a joint solicitation with the Earth Science Division's Research & Analysis program focused on enabling Earth science community support to the United Nations Sustainable Development Goals. FY 2018 will be the first full year of the applications consortium for food security and applications as well as for projects related to the GEO Work Programme.

The Applications project will continue its engagement with the applications community as part of current and future NASA Earth science missions, and it will support satellite mission teams to implement new guidance on the inclusion of applications in flight mission concepts. The project will review its communications efforts. The project will have the first results from the consortium on socioeconomic impact assessments. In FY 2018, the project will conclude a dedicated Wildland Fires applications area and shift those activities into the Ecological Forecasting and the Disaster applications areas.

Applied Sciences will deliver results in projects focused on water resource decisions with an emphasis on drought. The projects address advances in the long-term (30-180 day) outlooks of water supply anomalies and their effective use by water managers, their organizations, and decision-makers. The program will deliver results in projects focused on use of Earth observations in health and air quality, and the Health and Air Quality Applied Sciences Team will deliver results from its tiger team projects.

FY 2018 will be the first full year for work on agriculture and food security, for work supporting the Group on Earth Observations' Work Programme, and for work on the Sustainable Development Goals. The Program will have the first results from the consortium on socioeconomic impact assessments.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

Sixteen projects in the second SERVIR Applied Sciences Team will deliver results on projects done in partnership with regional hubs in Eastern Africa, Western Africa, Lower Mekong River, and Himalayan-Hindu Kush; the projects address food security, weather and climate, disasters, and water management. FY 2019 will also likely be the first full year for the new Amazonia SERVIR hub.

Eleven projects in the Ecological Forecasting applications area and eight projects in the Water Resources applications area will produce results. The Applications project will deliver results from core Health and Air Quality Applied Sciences Team projects focused on use of Earth observations in health and air quality. Projects supporting the U.S. contributions to the GEO Work Programme will deliver initial results.

Program Elements

CAPACITY BUILDING

The Capacity Building project enhances U.S. and developing countries' capacity, including human, scientific, technological, institutional, and resource capabilities, to make decisions informed by earth science data and models. Capacity Building builds skills in current and future workforce, and it creates opportunities in under-served areas to broaden the benefits of Earth observations. This project supports training, information product development, internships, data access tools, short-term application test projects, user engagement, and partnership development. This project has three primary elements: SERVIR for supporting developing countries, ARSET for professional-level training on Earth observations, and DEVELOP for workforce development through hands-on internships with state and local governments.

MISSION AND APPLIED RESEARCH

The Mission and Applied Research project enables involvement by applications-oriented users in the planning, development, and other activities of Earth Science satellite missions. The Mission and Applied Research project enables end user engagement to identify applications early and throughout mission life cycle, integrate end-user needs in design and development, enable user feedback, and broaden advocacy. Mission and Applied Research organizes community workshops to identify priority needs as well as studies to inform design trade-offs and identify ways to increase the applications value of missions. In this project, Applied Sciences advises flight projects on activities to develop the applications dimension of the mission to help broaden benefits and maximize the return from the investment in the mission.

DISASTER SUPPORT

The Disaster Support project enables development of innovative applications using NASA satellite mission data to ensure timely, valuable support to responders when disasters occur. The Disaster Support project sponsors the use and integration of Earth observations in disaster-related organizations' decisions and actions, including use of feasibility studies, in-depth projects, workshops, and needs assessments. The project also sponsors activities to improve a preparatory-based approach to enhance value and usability of NASA Earth Science products in support of disaster response and recovery. This project pursues partnerships with disaster groups that can carry forward NASA-developed information and tools to support the responders they serve.

APPLICATIONS

The Applications project organizes its development activities on priority themes related to societal and economic topics important to end user communities and their management, policy, and business activities. The Applications project sponsors the integration of Earth observations in community organizations' decisions and actions. Specific topics within an area evolve to reflect new priorities and opportunities. There are four formal applications areas in Ecosystems, Health, Water Resources, and Food Security. The project will conduct ad hoc activities on other themes and formalize areas when warranted or additional resources are available. Each applications area supports feasibility studies, in-depth projects, applied science teams, consortia, workshops, and needs assessments. Each applications area participates in major conferences and events that their partners attend in order to meet and engage managers and users.

Program Schedule

Date	Significant Event
FY 2018 Q2	ROSES-2018 selection no earlier than six months of receipt of proposals
FY 2019 Q2	ROSES-2019 selection no earlier than six months of receipt of proposals
FY 2020 Q2	ROSES-2020 selection no earlier than six months of receipt of proposals
FY 2021 Q2	ROSES-2021 selection no earlier than six months of receipt of proposals
FY 2022 Q2	ROSES-2022 selection no earlier than six months after receipt of proposals
FY 2023 Q2	ROSES-2023 selection no earlier than six months after receipt of proposals

Program Management & Commitments

Program Element	Provider
Applications	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): U.S. Forest Service, National Park Service, U.S. Department of Agriculture, NOAA, USGS, U.S. Fish and Wildlife Service, Environmental Protection Agency (EPA), Bureau of Land Management, Centers for Disease Control and Prevention.
Capacity Building	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): USAID
Disaster Support	Provider: Various Lead Center: HQ Performing Center(s): GSFC, JPL, LaRC, MSFC, Cost Share Partner(s): Department of Homeland Security (DHS), NOAA, USDA, USGS, USAID
Mission and Applied Research	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC, Cost Share Partner(s): USDA, CNES, ISRO, Joint Research Centre (JRC)

Acquisition Strategy

NASA bases the Earth Science Applied Science acquisitions on full and open competition. Grants are peer reviewed and selected based on NASA research announcements and other related announcements.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Relevance	Applied Sciences Advisory Committee	June 2017	Review strategy and implementation. Reports to NASA SMD/Earth Science Division Director.	Review examples of Applications topic in NAS Continuity Study	Feb 2018; semi-annual
Relevance	Applied Sciences Advisory Committee	February 2018	Review strategy and implementation. Reports to NASA SMD/Earth Science Division Director.	TBD	Feb 2020; semi-annual

PLANETARY SCIENCE

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	FY 2020	Notional FY 2021	FY 2022	FY 2023
Planetary Science Research	230.1	--	**258.0**	247.6	247.6	247.6	247.6
Planetary Defense	60.0	--	**150.0**	150.0	150.0	150.0	150.0
Lunar Discovery and Exploration	19.0	--	**218.0**	218.0	218.0	218.0	218.0
Discovery	194.6	--	**381.2**	476.6	375.0	355.6	348.5
New Frontiers	134.0	--	**130.2**	163.7	245.0	327.6	388.4
Mars Exploration	647.0	--	**601.5**	529.7	371.9	290.8	215.3
Outer Planets and Ocean Worlds	359.5	--	**285.6**	213.8	373.3	372.5	375.5
Technology	183.3	--	**210.2**	200.2	200.0	200.0	200.0
Total Budget	**1827.5**	**--**	**2234.7**	**2199.6**	**2180.8**	**2162.1**	**2143.3**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Planetary Science

PLANETARY SCIENCE RESEARCH

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Planetary Science Research and Analysis	178.1	--	**210.3**	190.7	190.2	184.1	182.9
Other Missions and Data Analysis	52.0	--	**47.7**	56.9	57.4	63.5	64.7
Total Budget	**230.1**	**--**	**258.0**	**247.6**	**247.6**	**247.6**	**247.6**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

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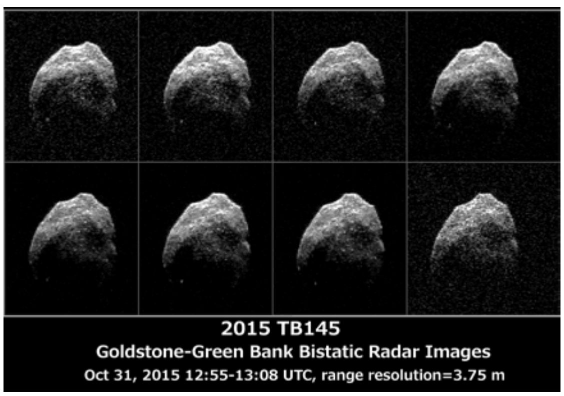

This high-resolution radar image of asteroid 2015 TB145 on a safe flyby of Earth on October 31, 2015, at about 1.3 lunar distances (300,000 miles, or 480,000 kilometers) was obtained by NASA scientists using the 230-foot (70-meter) Deep Space Network antenna at Goldstone, California, to transmit high-power microwaves toward the asteroid, from which the signal bounced back to Earth and its radar echoes were received by the National Radio Astronomy Observatory's 100-meter (330-foot) Green Bank Telescope in West Virginia. The radar image achieves a spatial resolution as fine as 13 feet (4 meters) per pixel and shows that asteroid 2015 TB145 is spherical in shape and approximately 2,000 feet (600 meters) in size, and reveals pronounced concavities, bright spots that might be boulders, and other complex features that could be ridges.

The Planetary Science Research program provides the scientific foundation for data returned from NASA missions exploring the solar system. It is also NASA’s primary interface with university faculty and graduate students in this field and the research community in general. The program develops analytical and theoretical tools, as well as laboratory data, to support analysis of flight mission data. These capabilities allow Planetary Science to answer specific questions about, and increase the understanding of, the origin and evolution of the solar system. The research program achieves this by supporting research grants solicited annually and subjected to a competitive peer review before selection and award. The Planetary Science Research program focuses on five key research goals:

- Explore and observe the objects in the solar system to understand how they formed and evolved;
- Advance the understanding of how the chemical and physical processes in our solar system operate, interact, and evolve;
- Explore and find locations where life could have existed or could exist today;
- Improve our understanding of the origin and evolution of life on Earth to guide our search for life elsewhere; and
- Identify and characterize objects in the solar system that pose threats to Earth or offer resources for human exploration.

PLANETARY SCIENCE RESEARCH

EXPLANATION OF MAJOR CHANGES IN FY 2019

Near Earth Object Observations, formerly part of this Program, is now part of the Planetary Defense Program. Planetary R&A includes an increase for lunar research.

ACHIEVEMENTS IN FY 2017

Although it is unknown when or where life on Earth began, geologists recently discovered putative microfossils, evidence for ancient life, in Greenland's rocks dating back 3.7 billion years. The fossils were part of an outcrop of ancient rock that had lost its usual snow cover. The rock layer forming the outcrop, known to geologists as the Isua supracrustal belt, lies on the southwest coast of Greenland and is some 3.9 to 3.7 billion years old. A second line of evidence came from what is likely some of the earliest habitable environments, submarine-hydrothermal vents. Astrobiologists have found putative fossilized microorganisms that are at least 3.77 billion and possibly 4.28 billion years old in ferruginous sedimentary rocks, interpreted as seafloor-hydrothermal vent-related precipitates, from the Nuvvuagittuq belt in Quebec, Canada. These structures occur as micrometer-scale tubes and filaments with morphologies and mineral assemblages similar to those of filamentous microorganisms from modern hydrothermal vent precipitates and analogous microfossils in younger rocks. The Nuvvuagittuq rocks contain isotopically light carbon in carbonate and carbonaceous material associated with the putative microfossils and provide evidence for biological activity in submarine-hydrothermal environments more than 3.77 billion years ago.

Water ice in lunar polar regions may provide a valuable resource for planetary exploration. Humans can convert water to propellant to fuel exploration and it is essential for life support. Finding accessible concentrations of water can enable exploration by reducing the amount of material launched from Earth when explorers can use local material instead. The Lunar Orbiter Laser Altimeter (LOLA) onboard the Lunar Reconnaissance Orbiter shines laser light onto the surface of the Moon and observes the reflected light. Analysis of these LOLA observations reveal higher reflectivity than lunar regolith, indicating water ice. Within 5° of the South Pole, there is a correlation between a brightening of the surface and colder temperatures. The more reflective surfaces also correlate to regions previously identified to be potential exposed frost on the surface by LRO LAMP data. Thus now three data sets from LRO—Diviner temperature data, LAMP far-ultraviolet spectra, and LOLA near-IR reflectance—agree that water ice is exposed in regions of near the lunar south pole where the temperature is cold enough for water ice to be stable on the surface.

Remotely analyzing the composition of atmospheres on far distant exoplanets to try to detect life requires the development of convincing biosignatures of biospheres on such planets. Scientists consider chemical disequilibrium via large production fluxes of chemically incompatible gases to be a signature of continuous biological processes. The most frequently cited example of this concept is the coexistence of molecular oxygen (O2) and methane (CH4) here on Earth. While the potential for remote detectability of O2/O3, CH4, and O2 - CH4 at the same time exists, these relationships have not been the same throughout Earth's history, based on recent results and coupled Earth-system models. Earth's O2 only recently became detectable during the Phanerozoic eon, while CH4 detection beyond the Archean would have been unlikely. O3 is possibly detectable for the second half of Earth's history, but detection could have been problematic depending on whether O2 approached the upper or lower estimate during the mid-Proterozoic. Thus, as we assess exoplanets, we must take into account that their potential biosignatures are not likely to be uniform over the life history of a planet.

PLANETARY SCIENCE RESEARCH

Lichens are globally critical organisms found within weathering rocks where few other organisms can live (i.e., the highest mountains in the world). For almost 150 years, scientists have considered lichens to be composed of a fungus partner and a photosynthetic microorganism or algae partner. They recently discovered that a third partner, a yeast organism, is also participating in this important symbiosis, finding it in a wide variety of habitats on six continents.

WORK IN PROGRESS IN FY 2018

In pursuit of fundamental science that guides planetary exploration, the Planetary Science Research program will continue to select highly rated R&A proposals that support planetary missions and goals. Planetary science will continue archiving and distributing relevant mission data to the science community and the public in a timely manner.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

In pursuit of fundamental science that guides planetary exploration, the Planetary Science Research program will continue to select highly rated R&A proposals that support planetary missions and goals. Planetary science will continue archiving and distributing relevant mission data to the science community and the public in a timely manner.

Program Elements

PLANETARY SCIENCE RESEARCH AND ANALYSIS (R&A)

Planetary Science R&A enhances the scientific return from on-going and completed spaceflight missions and provides the foundation for the formulation of new scientific questions and strategies for answering those questions. R&A develops new theories and instrumentation concepts that enable the next generation of spaceflight missions. R&A funds research tasks in areas such as astrobiology and cosmochemistry; the origins and evolution of planetary systems; the observation and characterization of extra-solar planets (i.e. exoplanets) and the atmospheres, geology, and chemistry of the solar system’s bodies other than the Earth or the Sun.

PLANETARY SCIENCE RESEARCH

Program Schedule

The Planetary Science Research Program will conduct its next call for research proposals as part of the Science Mission Directorate's annual Research Opportunities in Space and Earth Sciences (ROSES) research calls in 2018.

Program Management & Commitments

Program Element	Provider
R&A	Provider: NASA Lead Center: Headquarters (HQ) Performing Center(s): Ames Research Center (ARC), Glenn Research Center (GRC), Goddard Space Flight Center (GSFC), JPL, Johnson Space Center (JSC), Langley Research Center (LaRC), Marshall Space Flight Center (MSFC), HQ Cost Share Partner(s): N/A

Acquisition Strategy

The R&A budget will fund competitively selected activities from the ROSES omnibus research announcement.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Planetary Science Advisory Committee (PAC)	2017	Review to assess progress against strategic objectives of Planetary Science.	Recommendation was to maintain a strong program consistent with the decadal survey.	2018

OTHER MISSIONS AND DATA ANALYSIS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Joint Robotics Program for Exploration	9.1	--	**0.0**	0.0	0.0	0.0	0.0
Planetary Science Directed R&T	0.0	--	**11.1**	23.2	23.2	28.9	29.6
Science Innovation Fund	5.0	--	**0.0**	0.0	0.0	0.0	0.0
Planetary Data System	14.5	--	**17.0**	17.1	17.2	17.3	17.4
Astromaterial Curation	9.1	--	**11.8**	9.8	10.1	10.4	10.7
Science Data & Computing	2.4	--	**2.7**	2.7	2.8	2.8	2.9
Rosetta	7.8	--	**1.0**	0.0	0.0	0.0	0.0
Robotics Alliance	4.1	--	**4.1**	4.1	4.1	4.1	4.1
Total Budget	**52.0**	**--**	**47.7**	**56.9**	**57.4**	**63.5**	**64.7**

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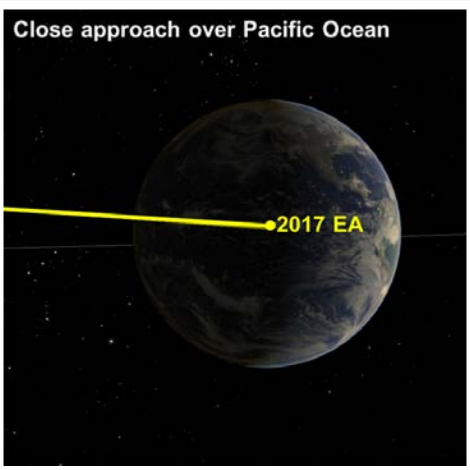

On March 2, 2017, asteroid 2017 EA, a small near-Earth asteroid less than 3 meters across, passed by Earth at a distance so close that it passed well inside the ring of geosynchronous satellites. Astronomers at the Catalina Sky Survey near Tucson, Arizona detected it only 6 hours before closest approach. At its closest point, this asteroid was 20 times closer than the Moon.

Other Missions and Data Analysis includes supporting mission functions such as Planetary Data Systems, Science Data and Computing, and Astromaterial Curation, as well as the NASA portion of the European Space Agency (ESA) Rosetta mission.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

Mission Planning and Other Projects

ROBOTICS ALLIANCE PROJECT

The Robotics Alliance Project (RAP) is dedicated to increasing interest in engineering, technology, science, and mathematics disciplines among youth in the United States. RAP's goal is to create an inspired, experienced technical workforce for the aerospace community, fostering the growth of a new national economic engine. Annual activities and events expose students to challenging applications of engineering and science. The Robotics

OTHER MISSIONS AND DATA ANALYSIS

Alliance Project supports national robotic competitions in which high school students team with engineering and technical professionals from government, industry, and universities to gain hands-on experience and mentoring.

Recent Achievements

In FY 2017 RAP sponsored 280 FIRST Robotics Competition teams (approximately 7,000 students), 50 VEX robotics teams (approximately 500 students), and sponsored and/or supported 18 FIRST Robotics Competition events (affecting approximately 45,000 students).

PLANETARY SCIENCE DIRECTED RESEARCH AND TECHNOLOGY

This project funds the civil service staff that will work on emerging Planetary Science flight projects, instruments, and research. The workforce and funding will transfer to projects by the beginning of FY 2019.

PLANETARY DATA SYSTEM (PDS)

The PDS is an online data archive. Scientists with expertise in planetary science disciplines designed the PDS, and they curate its data. The PDS furthers NASA's Planetary Science goals by efficiently collecting, archiving, and making accessible digital data produced by, or relevant to, NASA's planetary missions, research programs, and data analysis. The archives include imaging experiments, magnetic and gravity field measurements, orbit data, and various spectroscopic observations. All space-borne data from over 50 years of NASA-funded exploration of comets, asteroids, moons, and planets is publicly available through the PDS archive.

Recent Achievements

PDS has received data from 16 planetary missions in 2017. PDS also received data sets from ground-based observations, laboratory data, and higher order data sets from NASA data analysis investigations. The archive grew by approximately 200 TB to a total holding of approximately 1.3 Petabytes.

ASTROMATERIAL CURATION

The Astromaterials Acquisition and Curation Office at JSC curates all extraterrestrial material and space-exposed flight hardware under NASA control. Curation is an integral part of all sample return missions. Activities conducted by the Curation Office range from research into advanced curation techniques to support future missions, sample-return-mission planning, archiving of engineering and reference materials, recovery and transport of returned materials, initial characterization of new samples, preparation and allocation of samples for research, and providing clean and secure storage for the benefit of current and future generations. Samples currently include Antarctic meteorites, cosmic dust, and returned samples from the Moon (Apollo and Luna), the Sun (solar wind captured by Genesis), a comet (Stardust), an asteroid (Hayabusa), and interplanetary dust (on space-exposed hardware). Planning and research are currently underway for future curation of samples from asteroids (Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx and Hayabusa2), Mars, Mars' moons (MMX), and comets; Hayabusa2 and MMX samples are planned under international

OTHER MISSIONS AND DATA ANALYSIS

agreements with JAXA. New laboratory space is being constructed and outfitted within the Curation facility to prepare for receipt of the OSIRIS-REx and Hayabusa 2 materials.

Recent Achievements

In the past year, the Curation Office began the design phase for new advanced-curation and advanced-cleaning facilities to support upcoming sample return missions, and installed and began operating a new X-ray CT scanner for astromaterials (the first facility of its type in the world dedicated to astromaterials). The Curation Office is developing techniques for a new, state-of-the-art micromanipulator, applied new high-resolution 3D imaging techniques to two collections, and initiated advanced curation activities for contamination control (including organics and microbiological characterization of existing labs). This is in addition to maintaining 8 collections and 22 clean rooms, and, over the past year, allocating nearly 1400 samples to over 400 registered PIs from around the world.

SCIENCE DATA AND COMPUTING

This project, through the National Space Science Data Center (NSSDC), preserves NASA's science data collected since the first robotic missions in the 1960s. The NSSDC also serves as the back-up archive for the PDS. In addition to being a depository that makes unique data and metadata available, the NSSDC provides the space science community with stewardship, guidance, and support so that data made available to the research community is well documented to provide independent usability.

Recent Achievements

The NSSDC is currently working to convert many of the original data sets, which exist in analog form in their original media, to digital data sets accessible on-line by researchers. The PDS Lunar Data Node is charged with restoring old Apollo data, packaging the data, and overseeing their archive with PDS. This involves reading the data, converting it to standard digital formats, and collecting and making sense of the data formats and documentation so the data can be easily accessed and used by researchers. Currently we have completed archive of 12 data sets with PDS, completed packaging of 18 data sets in PDS compliant format, now awaiting review or lien resolution circa March 2018, and have restored and are in the process of packaging 9 data sets which should undergo review in the summer of 2018.

ROSETTA

Rosetta is an ESA-led comet rendezvous mission, with NASA participation, in its operations phase. It launched in March 2004, and has enabled scientists to look at some of the most primitive material from the formation of the solar system 4,600 million years ago. Rosetta is studying the nature and origin of comets, the relationship between cometary and interstellar material, and the implications of comets with regard to the origin of the solar system. The Rosetta spacecraft is the first to undertake long-term exploration of a comet at close quarters. It comprises a large orbiter designed to operate for a decade at large distances from the Sun, and a small lander. Each of these elements carries a large number of scientific experiments and examinations designed to complete the most detailed study of a comet ever attempted. Rosetta arrived at comet 67P/Churyumov–Gerasimenko in FY 2014. The operational phase of the mission ended with the controlled descent of the spacecraft onto the comet at the end of FY 2016.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

Science data analysis continued in FY 2017 with the Rosetta Data Analysis Program AO released in the fall of 2017. Scientists are comparing remote sensing with in-situ data to improve the understanding of cometary behavior and activity, particularly before and after the perihelion phases. The Rosetta mission will end at the end of FY 2018.

PLANETARY DEFENSE

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
DART	0.0	--	**90.0**	71.0	48.0	8.0	2.0
Other Missions and Data Analysis	60.0	--	**60.0**	79.0	102.0	142.0	148.0
Total Budget	**60.0**	**--**	**150.0**	**150.0**	**150.0**	**150.0**	**150.0**

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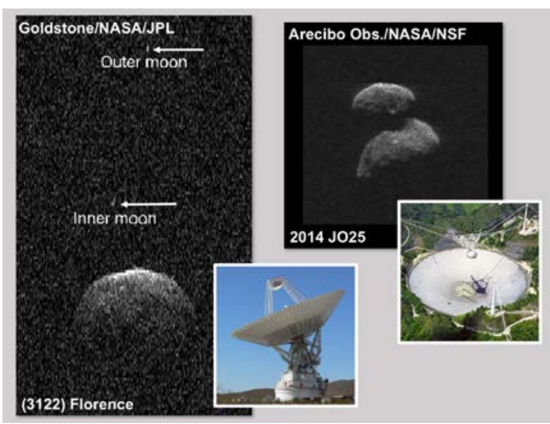

Planetary radar images of large asteroids during close-approach to Earth. (Left) Goldstone radar imagery of asteroid (3122) Florence, which measures 2.8 miles in rough diameter, revealed surface features along with two moons orbiting the asteroid and measuring ~300-1000 feet in size. Florence passed 4.4 million miles from Earth on September 1, 2017 and was the largest asteroid to make such a close approach since NASA began its Near-Earth Object Observations program in 1998. (Right) Arecibo radar imagery of asteroid 2014 JO25, which approached Earth on April 19, 2017 at 1.1 million miles, less than 4.6 times the distance to the Moon. Measuring ~950 meters long, its asymmetric, two-lobed structure might indicate a contact binary and is reminiscent of the target of ESA's Rosetta mission, comet 67P/Churyumov-Gerasimenko.

The focus of planetary defense missions is centered upon the initial detection and subsequent follow-up observations for precision orbit determination and physical characterization of asteroids and comets with the potential to impact the Earth, as well as mounting efforts (from civil disaster response preparations to in space object deflection or disruption missions) to mitigate the effects of an impending near-Earth object (NEO) impact event.

The NASA Planetary Defense program is managed by the Planetary Defense Coordination Office (PDCO). PDCO administers the Near-Earth Object Observations (NEOO) project, which funds and coordinates efforts to find, track and characterize any asteroid or comet that could become an impact hazard to Earth. Scientists conduct these NEO observation efforts at observatories supported by NASA on the ground and in space, as well as by the National Science Foundation and space situational awareness facilities of the United States Air Force. In addition to finding, tracking, and characterizing NEOs, NASA's planetary defense goals include researching techniques for deflecting or disrupting, if possible, potentially hazardous objects (PHOs) that are determined to be on an impact course with Earth to provide options for US government response to any detected impact threat. In the event that deflection or disruption is not possible due to too short of time available before impact, the PDCO is responsible for providing expert input to other government agencies such as the Federal

Emergency Management Agency for emergency response operations, should a PHO be on an impact course or actually impact Earth.

Planetary Defense program responsibilities include:

- Ensuring the early detection of PHOs—asteroids and comets whose orbit are predicted to bring them within 0.05 Astronomical Units of Earth, and of a size large enough to reach Earth's surface (i.e., greater than perhaps 30 to 50 meters);
- Tracking and characterizing PHOs and issuing warnings about potential impacts;
- Providing timely and accurate communications about PHOs; and
- Performing as a lead coordination node in U.S. Government planning for response to an actual impact threat. See https://www.nasa.gov/planetarydefense/overview

EXPLANATION OF MAJOR CHANGES IN FY 2019

NASA has established a new Planetary Defense Program to manage all aspects of the effort, from finding and tracking hazardous NEOs to demonstration of space technologies to deflect or disrupt one. This currently includes the Double Asteroid Redirection Test and Near-Earth Object Observations projects. The Double Asteroid Redirection Test is a demonstration of an asteroid deflection technology, using the kinetic impactor technique to change the orbit of a small moon circling the asteroid Didymos. The Near-Earth Object Observations project will continue to fund ground-based NEO discovery, tracking, and characterization efforts, while also enabling the development of future space-based NEO detection missions.

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	FY 2020	Notional FY 2021	FY 2022	FY 2023
Total Budget	0.0	--	90.0	71.0	48.0	8.0	2.0

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

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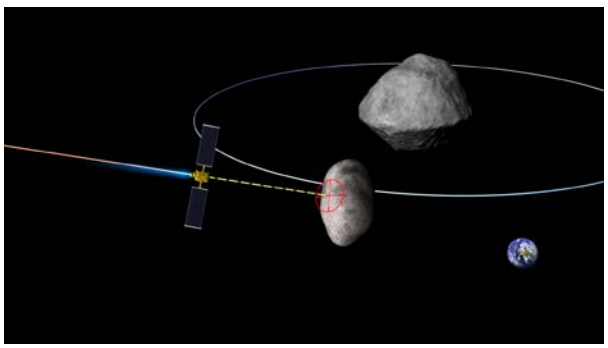


Artists depiction (not to scale) of the DART spacecraft approaching impact with the moonlet of the double asteroid Didymos at a time when Didymos is close enough to the Earth to allow ground-based telescopes to measure the change in the moonlet's orbit caused by the impact.

PROJECT PURPOSE

The Double Asteroid Redirection Test (DART) is the first planetary defense mission, demonstrating the kinetic impact technique to change the motion of an asteroid in space. The target asteroid for DART is the double Asteroid Didymos. The Didymos system consists of the primary asteroid Didymos that is about 780 meters (1/2 mile) in diameter and a "moonlet" that is about 163 meters (535 feet) in diameter. The DART spacecraft will demonstrate the kinetic impact deflection method by deliberately crashing into the moonlet at a speed of approximately 6 kilometers per second (13,000 miles per hour), with the aid of an onboard camera and sophisticated autonomous navigation software. The collision will change the orbital period of the moonlet for its orbit around the main body by a fraction of one percent, enough to be measured using telescopes on Earth. By targeting the small moonlet in a binary system, the DART mission plan makes this demonstration possible without changing the orbit of the system about the Sun. The DART mission will demonstrate the effectiveness of the kinetic impact technique for deflecting a hazardous asteroid and NASA will use it to improve our readiness to respond to an actual asteroid impact threat.

NASA's DART spacecraft has a launch readiness date range from late December 2020 to May 2021 and a launch period of 5-7 months. The targeted impact date with the Didymos system moonlet is October 2022, when the Didymos system is within 11 million kilometers of Earth, enabling observations by ground-based telescopes and planetary radar.

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2019

NASA has moved the DART project from the Planetary Research Program into the Planetary Defense Program.

PROJECT PRELIMINARY PARAMETERS

NASA plans to launch DART as a secondary payload sometime between December 2020 and May 2021. DART carries a single camera, the Didymos Reconnaissance and Asteroid Camera for OpNav (DRACO), used by the DART SMARTNav system to guide the spacecraft to impact the moonlet of the double asteroid Didymos. DART will use X-Band communications through the NASA Deep Space Network (DSN) to downlink the DRACO images prior to impact, which will allow the reconstruction of where on the moonlet the impact occurred. The DART spacecraft will utilize the NASA Evolutionary Xenon Thruster – Commercial (NEXT-C) solar electric propulsion system as its primary in-space propulsion system. NEXT-C based its next generation system on the Dawn spacecraft propulsion system. The NEXT-C propulsion system provides the DART project with significant flexibility in the mission timeline, including significantly widening the viable launch period (compared to most planetary missions), as well as decreasing the cost of the launch service. Researchers will measure the change in the orbital period of the moonlet caused by the impact during the 2022 Didymos double asteroid close pass by the Earth, using the world-wide network of optical and radio telescopes.

ACHIEVEMENTS IN FY 2017

DART completed its Phase A concept study and was approved to enter into Phase B preliminary design and technology completion.

WORK IN PROGRESS IN FY 2018

DART transitioned from the Near Earth Object Observations (NEOO) Program to the Planetary Defense Program, managed by the Planetary Missions Program Office.

The DART asteroid deflection technology demonstration will complete Phase B design and pass confirmation to begin Phase C full-scale final design and fabrication (development) activities.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

DART will complete detailed design and fabrication activities, its critical design review and mission operations review in preparation to pass the KDP-D gate review in FY 2020 to begin Phase D spacecraft assembly, integration and test activities.

ESTIMATED PROJECT SCHEDULE

All dates are preliminary.

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

Milestone	Formulation Authorization Document	FY 2019 PB Request
Formulation Authorization	March 2016 (Rev B)	
MCR	May 2015	May 2015
SRR/MDR	August 2016	September 2016
KDP-B	October 2016	March 2017
PDR	February 2018	April 2018
KDP-C	February 2018	May 2018
CDR	December 2018	March 2019
KDP-D	November 2019	December 2019
FRR	Early December 2020	December 2020 - May 2021
Launch Readiness	December 2020	December 2020 - May 2021
KDP-E	January 2021	Launch + 1 month
Asteroid Impact/End of Flight Operations	October 2022	October 2022
End of Ground Observations and Data Analysis		July 2023

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or preliminary design review. The lifecycle cost of DART does not include the cost of the NEXT-C propulsion system, which DART will use as a demonstration of a new propulsion technology. Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or preliminary design review.

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
June 2017	248 - 291	Launch	December 2020 to May 2021

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

Project Management & Commitments

The Principal Investigator is from John Hopkins University/Applied Physics Laboratory and leads the management of the mission.

Element	Description	Provider Details	Change from Formulation Agreement
DART Project	DART Project design and implementation, with the exception of subcontracted subsystems and the government-provided NEXT-C electric propulsion system	Provider: JHU-APL Lead Center: JHU-APL Performing Center(s): JHU-APL Cost Share Partner(s): N/A	No
NEXT-C	Government-furnished electric propulsion system	Provider: Aerojet Lead Center: GRC Performing Center(s): GRC Cost Share Partner(s): PSD	Yes, NASA decision to use NEXT-C after approval of the Formulation Agreement Document (FAD)

Project Risks

Risk Statement	Mitigation
If: the SMARTNav autonomous guidance system used to guide the spacecraft during the final approach to impact is not sufficiently robust to variations in the observed binary system Then: the spacecraft may not hit the target	The Project has developed and is continuing to refine a high-fidelity emulator of the end-to-end performance of the DRACO camera, image processing pipeline, and SMARTNav algorithms. The Project is varying (in a Monte Carlo analysis) the characteristics of the Didymos system (size, shape, and albedo of each body, orbit characteristics, etc.), the approach conditions, and the DRACO and spacecraft parameters to demonstrate the robustness of the design to the range of variations that DART may encounter when it arrives at Didymos.

Acquisition Strategy

NASA is acquiring the flight system for the DART mission from JHU/APL. The acquisition of host launch capability with DART as a secondary payload is to be determined. NASA is acquiring the NEXT-C propulsion system via the GRC from Aerojet.

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Prime Contract, Mission Formulation, and Mission Implementation	JHU-APL	Laurel, MD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Institutional Review Team (IRT)	September 2016	System Requirements Review (SRR) to assess readiness for preliminary design and technology completion (Phase B)	After the SRR, NASA decided to establish the DART SRB and insert an SRB Status Review before approving KDP-B	PDR*
Performance	Standing Review Board (SRB)	February 2017	SRB Status Review to assess SRR results, progress/ resolution of SRR actions, changes since the SRR, and to assess readiness for Phase B	Successful, project ready to proceed to Phase B	PDR
Performance	Standing Review Board (SRB)	April 2018	Preliminary Design Review (PDR) to assess readiness for final design and fabrication (Phase C)		CDR
Performance	Standing Review Board (SRB)	March 2019	Critical Design Review (CDR) to assess readiness for to assess readiness for project to begin system assembly, integration, and test (start of Phase D)		ORR

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	October 2020	Operational Readiness Review (ORR) to assess readiness for system launch, checkout, (completion of Phase D), operations, and sustainment (Phase E)		

* After the SRR, NASA decided to establish the DART SRB and insert an SRB Status Review before approving KDP-B.

OTHER MISSIONS AND DATA ANALYSIS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Near Earth Object Observations	60.0	--	**60.0**	79.0	102.0	142.0	148.0
Total Budget	**60.0**	**--**	**60.0**	**79.0**	**102.0**	**142.0**	**148.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Mission Planning and Other Projects

NEAR-EARTH OBJECT OBSERVATION (NEOO)

The NEOO Project was established to detect and track at least 90 percent of the asteroids and comets greater than 140 meters in diameter that come within 1.3 astronomical units of the Sun (within about 30 million miles of Earth's orbit). The NEOO project, using ground and space-based assets, looks for NEOs that have any potential to collide with Earth and characterizes them to assess if any could do significant damage to the planet. NEOs range in size from a few meters to approximately 34 kilometers, with smaller objects being two orders of magnitude more numerous than larger objects.

The NEOO project supports a network of search and characterization observatories and the data processing and analysis required to understand the near-Earth population of small bodies. In accordance with the findings and recommendations of the January 2010 National Academies study on the NEO hazard, NASA continues to:

- Analyze the small body data collected by the reactivated WISE mission, now called NEOWISE, and support increased follow-up and analysis of this data;
- Increase collection of NEO detection and characterization data by the Catalina Sky Survey, the Panoramic Survey Telescope and Rapid Reporting System (Pan-STARRS) and the United States Air Force's (USAF) newly commissioned Space Surveillance Telescope;
- Support the operation of the two small telescope wide field survey system called the Asteroid Terrestrial-impact Last Alert System (ATLAS), designed to detect smaller asteroids as they approach the Earth and warn of any imminent impact;
- Support the continued and enhanced operation of planetary radar capabilities at the National Science Foundation's Arecibo and NASA's Goldstone facilities; and
- Investigate both ground and space-based concepts for increasing capacity to detect, track, and characterize NEOs of all sizes.

Since NASA's search started in 1998, the project has found over 94 percent of these objects that are 1 kilometer and larger, and about 30 percent of all those larger than 140 meters in size. The project also discovers and characterizes NEOs that could be viable targets for robotic and crewed exploration, and possible eventual candidates for asteroid mining operations.

For more information on NEOO: https://cneos.jpl.nasa.gov/about/search_program.html

The Infrared Telescope Facility (IRTF) is NASA's infrared-optimized 3-meter telescope sited at altitude of 13,600 feet on the extinct volcano Mauna Kea on the Big Island of Hawai'i. The University of Hawai'i Institute for Astronomy operates the IRTF for NASA under contract. The NEOO project funds IRTF operations and IRTF is a primary NASA planetary defense asset for NEO physical characterization. IRTF continues its mission of strategic support of NASA flight missions and science goals in both planetary science and astrophysics while being on-call for rapid response observations of NEO targets of opportunity and potential threats.

For more information on IRTF: http://irtfweb.ifa.hawaii.edu/

The NEOWISE mission uses the Wide-field Infrared Survey Explorer (WISE) spacecraft, a 40 cm (16 in) diameter infrared telescope in Earth-orbit that continues an all-sky astronomical survey with its two non-cryogenic detectors, which remain operational. The Jet Propulsion Laboratory operates the NEOWISE mission. NEOWISE capabilities and vantage point enable contribution to NEO discovery and more significantly physical properties of large numbers of NEOs, comets, main-belt asteroids, and other minor planets.

For more information on NEOWISE: https://www.nasa.gov/mission_pages/neowise/mission/index.html

The Near-Earth Object Camera (NEOCam) is a space-based 0.5-meter infrared telescope concept optimized for NEO search and characterization that could survey from the L1 Lagrange point between the Earth and the Sun. NEOCam is in Phase A study led by the Jet Propulsion Laboratory. However, the NEOCam concept is unaffordable in the current budget environment, and NASA is looking for ways to substantially reduce the costs before pursuing a NEO search mission. NASA intends to initiate development of a lower-cost space-based NEO search capability in FY 2019.

Recent Achievements

Asteroid search teams funded by the NEO Observations project found, in FY 2017, another six asteroids larger than one km in size with orbits that come close to Earth's vicinity. Asteroid search teams also found 1,850 asteroids less than one km in size, along with the first interstellar object observed passing through our Solar System. Observers found no additional Earth approaching comets. This brought the total known population of NEOs to 16,851 as of September 30, 2017. The high-precision orbit predictions computed by the Center for Near-Earth Object Studies at NASA's Jet Propulsion Laboratory (JPL) show that none of these objects is likely to strike the Earth in the next century. However, 1840 near-Earth asteroids (of which 157 are larger than one km in diameter), with 110 found in FY 2017, are in orbits that could become a hazard in the more distant future and warrant continued monitoring (i.e. they are potentially hazardous asteroids or PHAs).

The NEOO project conducted an exercise of the International Asteroid Warning Network that attracted involvement by observatories worldwide. Scientists predicted the small asteroid 2012 TC4, not observed since its discovery in 2012, would make a close approach to Earth on Oct. 12, 2017. Although determined there was no chance that 2012 TC4 would impact Earth, observers were not certain of its precise orbit, making it a good target for an exercise of a response to a potential impact threat. NEOO and worldwide assets worked to observe 2012 TC4 on its approach toward Earth (first recovered by the European Very Large Telescope in late July 2017) and precisely determine the closest approach distance. Other efforts included future orbit determination and hypothetical threat assessment (e.g., damage to Earth) based on the observations. NASA program executives exercised detection and observation status notifications up through NASA management to the Executive Office of the President and to other US government agencies, as outlined in NASA Policy Directive 8740.1 - "Notification and Communications Regarding Potential Near-Earth Object Threats".

Researchers studied other asteroids in detail during their close-approaches to Earth, characterizing small or potentially hazardous asteroids and yielding important new near-Earth asteroid discoveries. On March 2, 2017, asteroid 2017 EA, a few meters in size, dipped below the geosynchronous ring of satellites soon after discovery, passing within just 12,830 km (7,970 miles) of the Earth's surface at closest approach. On April 4, asteroid 2017 GM, 3-6 meters in size, was discovered just hours before passing within 9900 kilometers of Earth's surface and over the orbit plane of the ring of geosynchronous satellites. Observers of the Catalina Sky Survey discovered both of the asteroids. The potentially hazardous asteroid 3122 Florence made a close approach of 4.4 million miles (7.0 million kilometers) on September 1. At 2.7 miles (4.3 kilometers) in size, it was the largest asteroid to pass this close since the NEOO project began in 1998. Observations with the NEOO-funded Goldstone radar revealed that Florence has TWO satellites, making it only the third known trinary system in the near-Earth asteroid population. See https://cneos.jpl.nasa.gov/images/news/florence.arecibo.sep4.gif

NEOWISE completed its seventh full sky survey. Over 10 million sky images have been downlinked, processed for moving object detection, and archived. NEOWISE discovered 31 near-Earth asteroids and one comet in FY 2017.

NASA approved an Extended Phase A for the NEOCAM concept study to modify it from the original Discovery Program science proposal to focus exclusively on planetary defense asteroid and comet survey requirements, and advance technology development needs for the project, particularly in the development of the infrared focal plane detector.

WORK IN PROGRESS FY 2018

The first month of FY 2018 saw the discovery and confirmation of the first interstellar object seen passing through the solar system. The Pan-STARRS 1 telescope (atop Haleakala on Maui, Hawaii) discovered the interstellar interloper, provisionally designated A/2017 U1, on Oct. 18, 2017 during routine NEO survey operations. (Researchers later extracted two prior observations from routine NEO survey images by the Catalina Sky Survey near Tucson, Arizona, dated Oct. 14 and 17.) Several other telescopes also provided follow-up observations critical for interstellar trajectory determination and confirmation by the Minor Planet Center and JPL's Center for Near-Earth Object Studies. A/2017 U1, a "deep space asteroid" or possibly an extinct comet (no coma has been observed), is estimated to be less than ~0.5 kilometer in size.

The Pan-STARRS 2 telescope will begin routine NEO survey operations. Researchers expect to increase the discovery productivity of the project by about 50 percent with its use.

The NEOWISE spacecraft, whose orbit has been precessing away from the ideal sun synchronous orbit alignment since its year of prime operations in 2010, will reach a point where the Sun's light is reaching too far down into the telescope and the heat will effectively blind the infra-red detectors, terminating the

OTHER MISSIONS AND DATA ANALYSIS

useful life of the spacecraft. Precessing means a change in the orientation of the rotational axis of a rotating body.

NASA will continue to explore cost-effective options for a space-based NEO search capability, which could include a phased approach with a visible survey telescope focused on asteroid detection, followed later by an infrared telescope for follow-up characterization.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

NASA will continue to support a network of search and characterization observatories and the data processing and analysis required to understand the near-Earth population of small bodies. Depending on the outcome of studies conducted in FY 2018, NASA may initiate development of a space-based NEO search capability.

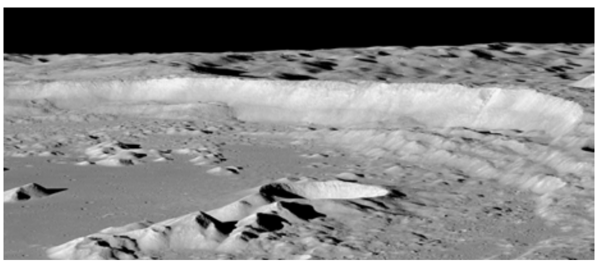
LUNAR DISCOVERY AND EXPLORATION

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Other Missions and Data Analysis	19.0	--	**218.0**	218.0	218.0	218.0	218.0
Total Budget	**19.0**	**--**	**218.0**	**218.0**	**218.0**	**218.0**	**218.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



The Moon, our nearest neighbor, a location rich in scientific interest and potential resources.

NASA's new Exploration Campaign will be an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system, and to bring new knowledge and opportunities back to Earth. This will be accomplished through public-private partnerships with the emerging commercial capabilities and innovative approaches to achieving human and science exploration goals, including the eventual return of humans to the moon. The Lunar Discovery and Exploration program in Science is a key component of the Exploration Campaign, and will support activities such as the establishment of commercial contracts for transportation services, the development of small rovers to be delivered via commercial landers, and the building and launching of instruments that serve lunar science, long-term exploration and utilization needs.

The Moon is a stepping-stone, a training ground, and a venue to strengthen our commercial and international partnerships. As the nation turns its attention back toward our nearest celestial neighbor, we will renew our exploration of Earth’s natural satellite.

To begin this journey, instruments, experiments, or other payloads on the lunar surface can address the variety of exploration, science, technology demonstration, and utilization objectives identified by NASA. In partnership with US industry and the scientific community, the Lunar Discovery and Exploration Program will develop lunar surface payloads (and supporting orbital payloads), along with cost-effective ways to deliver and provide services for these payloads. These payloads and services will address the nation’s lunar exploration, science, and technology demonstration goals, many of which are outlined in the National Academies of Sciences 2011 Decadal Survey: Vision and Voyages for Planetary Sciences in the Decade 2013-2022, and the National Research Council 2007 Report: The Scientific Context for the Exploration of the Moon and the NASA Strategic Knowledge Gaps (see https://www.nasa.gov/exploration/library/skg.html).

Through the Lunar Discovery and Exploration Program, NASA will solicit transportation and delivery services from Earth to the lunar surface for NASA payloads. NASA expects to fly NASA payloads or instruments on existing and forthcoming commercial missions and purchase transportation to the Moon for the NASA payloads or instruments (to include landing and surface access to agreed-upon locations on the lunar surface). NASA payloads will obtain "utilities" from commercial landers such as power, communications, thermal control, etc., during launch integration, launch, and cruise phase, and potentially after landing. In addition, NASA will pursue the purchase of science or engineering data provided by contractor payloads, and the return of payload and/or samples to the Earth. This approach offers NASA the potential to address critical strategic objectives related to exploration, science, and technology demonstration using commercially provided domestic space services and hardware.

In parallel with the development of commercial partnerships to provide lunar surface payload delivery and support services, the Lunar Discovery and Exploration Program will develop the exploration, science, and technology payloads to support this on-going investment. One area of focus will be instrumentation to advance the knowledge and technologies for the use of local resources, such as lunar water ice. Working with the science and human exploration communities, our international partners, and US industry, NASA will refine the goals and objectives for a robust lunar exploration and science program.

Explanation of Major Changes in FY 2019

In FY 2019, NASA will initiate the Lunar Discovery and Exploration Program, commencing new efforts to develop exploration, science, and technology payloads for delivery to the lunar surface. It will utilize US commercial capabilities to deliver these payloads, and integrate and coordinate NASA’s on-going lunar research and robotic mission activities.

Achievements in FY 2017

In FY 2017, NASA released the Lunar Surface Cargo Transportation Services Request for Information (RFI) soliciting information under this Request for Information (RFI) to determine the extent of interest and availability of domestic vendor sources capable of providing commercial launch and landing services on commercial missions to the lunar surface for NASA payloads.

NASA continued operations of the Lunar Reconnaissance Orbiter (LRO) under the Planetary Science Discovery Program. LRO continues to provide a treasure trove of lunar data that directly supports the advancement of lunar science and the planning of future lunar missions by helping to characterize and to conduct detailed surveys of potential landing sites for commercial missions.

Work in Progress in FY 2018

In FY 2018, NASA will follow up the Lunar Surface Cargo Transportation Services Request for Information (RFI) with a Request for Proposals (RFP) with the intent of establishing contracts for the purchase of commercial transportation and services to deliver NASA scientific, exploration, and technology payloads to the surface of the Moon.

NASA will work with the science community, NASA’s international exploration partners, and US industry to refine the exploration, scientific, and technology objectives in support of the Lunar Discovery and Exploration Program in FY 2019.

LUNAR DISCOVERY AND EXPLORATION

NASA will issue competitive solicitations to develop lunar surface payloads compatible with the expected commercial lunar surface cargo transportation services. Robotic payload proposals will be selected that advance NASA's exploration, scientific, and technology goals.

NASA will continue operations of LRO in support of scientific research and future science and exploration mission planning. Early in FY 2018 the scientific journal Icarus published Part III of the three-part Special Issue on the scientific results from LRO.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

In FY 2019, NASA will award contracts solicited through the FY 2018 Request for Proposals (RFP) enabling the purchase of commercial transportation and services to deliver NASA scientific, exploration, and technology payloads to the surface of the Moon.

NASA will competitively select robotic lunar surface payloads that advance NASA and U.S. industry's exploration, scientific, and technology goals to include resource utilization. These payloads will leverage the expected commercial lunar surface cargo transportation services for delivery to the lunar surface.

NASA will continue operations of LRO in support of scientific research and future science and exploration mission planning.

Program Schedule

Date	Significant Event
FY 2018	Request for proposal for commercial lunar payload services
End of FY 2018	Solicit robotic surface payloads
FY 2019	Award multiple IDIQ procurements for commercial lunar payload services
FY 2019	Award robotic surface payloads procurements

Program Management & Commitments

The Planetary Mission Program Office at MSFC will manage this program.

Program Element	Provider
Lunar Future	Provider: Lead Center: HQ Performing Center(s): Cost Share Partner(s):

LUNAR DISCOVERY AND EXPLORATION

Program Element	Provider
Lunar Reconnaissance Orbiter	Provider: Lead Center: GSFC Performing Center(s): GSFC, APL, JPL Cost Share Partner(s):
Commercial Lunar Payload Services	Provider: TBD Lead Center: JSC Performing Center(s): TBD Cost Share Partner(s): TBD

Acquisition Strategy

The Lunar Discovery and Exploration Program acquisition strategy is to establish flexible contract mechanisms, such as indefinite delivery, infinite quantity (IDIQ) contracts, that enable the flexible and rapid procurement of commercial transportation and services to deliver NASA scientific, exploration, and technology development payloads to the surface of the Moon, including potential supporting services and sample return.

In parallel, NASA will use its established solicitation mechanism, such as the Research Opportunities in Space and Earth Science (ROSES) NASA Research Announcement (NRA) and the Stand Alone Missions of Opportunity (SALMON) Announcement of Opportunity (AO) processes, to select and develop exploration, scientific, and technology development payloads for delivery to the Moon. In some cases, NASA may direct a NASA Center to develop a lunar capability or surface payload when it is in the government's interest, such as when that capability supports multiple NASA applications or when a commercial entity or international partner identifies a near-term opportunity for a lunar surface mission on a timeframe that does not support competitive selection. However, to the extent possible, NASA will leverage commercial efforts.

MAJOR CONTRACTS/AWARDS

None

Element	Vendor	Location (of work performance)
Program Management	Planetary Management Program Office	MSFC
Payload Services	TBD	JSC
Science and technology payload development	Planetary Management Program Office	MSFC

OTHER MISSIONS AND DATA ANALYSIS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Lunar Future	0.0	--	**200.0**	200.0	200.0	200.0	200.0
Lunar Reconnaissance Orbiter (LRO)	19.0	--	**18.0**	18.0	18.0	18.0	18.0
Total Budget	**19.0**	**--**	**218.0**	**218.0**	**218.0**	**218.0**	**218.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Mission Planning and Other Projects

LUNAR FUTURE

Lunar Future Missions will support public-private partnerships and innovative approaches to achieving human and science exploration goals, including the eventual return of humans to the moon. It will also support activities such as the establishment of commercial contracts for transportation services, the development of small rovers to be delivered via commercial landers, and the building and launching of instruments that serve lunar science and exploration needs. Example missions include deploying nodes for the Lunar Geophysical Network, a priority identified by the National Academy of Sciences; in situ investigation of potential lunar resources, a priority identified in the Exploration Strategic Knowledge Gaps; and the demonstration of technologies to enable long-term robotic missions on the lunar surface despite the power and thermal challenges imposed by the lunar night.

Operating Missions

LUNAR RECONNAISSANCE ORBITER (LRO)

Over the upcoming year, LRO will continue characterizing areas on the Moon that spend most of the time in shadow but that the Sun briefly illuminates for a few hours to a few days over the 18-year lunar precession cycle. If these measurements show that surface frosts change during and just after illumination, this will provide new constraints on the transport of polar volatiles. Another focus in the coming year will be to continue probing the vertical distribution of volatiles. Each of the instruments onboard LRO contributes to understanding volatiles by probing different depths, from coatings on the surface to volatiles mixed within the first few feet (about one meter) below the surface.

Having initiated a new operating mode for the ultraviolet instrument (the Lyman Alpha Mapping Project, or LAMP), allowing 80 times more light into the instrument during dayside observations, LRO will use this increased signal to improve our understanding of the day/night variability of the ultraviolet water signature on the lunar surface. LRO will continue work examining recent and ongoing surface changes and observing how the regolith (the loose material on the surface of the Moon) evolves over time. This includes additional measurements by LROC, Diviner, LAMP, and Mini-RF to determine if additional unique signatures of contemporary impact craters exist.

LRO's observations will continue to improve what we know about the interior of the Moon based on surface observations, by examining the interactions between the Moon and the space environment, the solar wind and galactic cosmic radiation.

Recent Achievements

The LRO mission continues to focus on lunar volatiles such as water ice, where these volatiles come from, how they move about on the lunar surface, and where they end up. By re-imaging the Moon to detect changes in the surface over the life of the mission, LRO continues to refine constraints on the rate at which meteor impacts disturb and overturn of the surface. The reimaging of sites captured by previous LRO camera images under similar lighting and viewing conditions creates temporal pairs and enables the automatic detection of surface changes. In addition to the new impact craters, these image pairs show extensive disturbances of the surface surrounding the new impact craters as well as distant secondary cratering. The imaging team (LROC) has uncovered several impact craters with ejecta blankets large enough for other instruments on board the spacecraft to observe them. The Diviner team has found that these areas exhibit unusual thermal properties, probably related to how ejecta initially connect themselves (thermally) to the underlying surface. Scientists are using additional measurements by LAMP and Mini-RF to determine if other unique signatures of contemporary impact craters exist. These results are unique to LRO, in that only a mission with an extended baseline of high-resolution observations can generate the necessary coverage over time to discover such changes.

DISCOVERY

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
InSight	32.3	109.4	**22.3**	11.8	9.0	9.0	9.0
Lucy	54.5	--	**153.3**	209.8	154.7	56.4	16.5
Psyche	47.3	--	**171.2**	214.6	173.3	163.0	40.1
Other Missions and Data Analysis	60.5	--	**34.4**	40.4	38.0	127.2	282.9
Total Budget	**194.6**	**--**	**381.2**	**476.6**	**375.0**	**355.6**	**348.5**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

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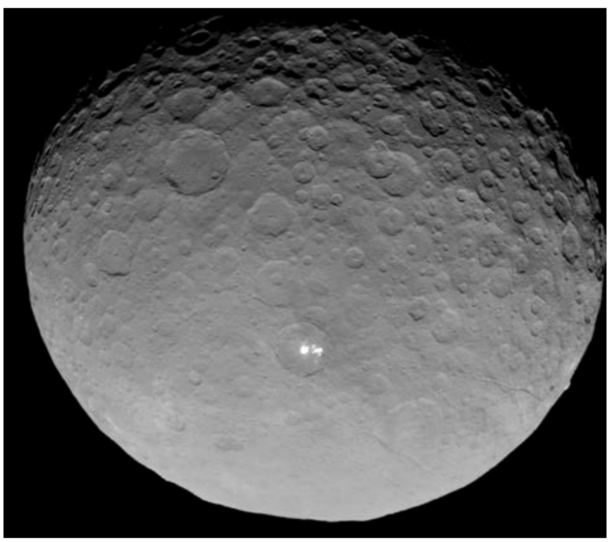


All completed Discovery missions have achieved ground-breaking science, each taking a unique approach to space exploration, doing what's never been done before, and driving new technology innovations . The Dawn spacecraft gently settled into orbit at the dwarf planet Ceres in early March 2015 to begin its 16-month study of this largest object in the main asteroid belt. Early images revealed a heavily cratered surface and enigmatic bright spots. Clay-like minerals with little or no obvious ice dominates the surface, which has scientists rethinking the formation and evolution history and the internal structure of this small world.

NASA's Discovery program supports innovative, relatively low-cost, competitively selected Planetary Science missions. Discovery provides scientists the opportunity to identify innovative ways to unlock the mysteries of the solar system through missions to explore the planets, their moons, and small bodies such as comets and asteroids.

The Discovery program currently has one operational spacecraft: Dawn; two mission(s) in formulation: Lucy and Psyche; and one flight mission in development: the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight). The program has also developed and delivered the Strofio instrument as a part of ESA's BepiColombo mission to Mercury. NASA and JAXA are engaged in joint studies for NASA's participation in the MMX mission to the moons of Mars, planned for launch in 2024. NASA has competitively selected MEGANE, a neutron and gamma ray spectrograph, for flight on the MMX spacecraft.

DISCOVERY

EXPLANATION OF MAJOR CHANGES IN FY 2019

The Lunar Reconnaissance Orbiter (LRO) mission has moved into the Lunar Discovery and Exploration Program.

ACHIEVEMENTS IN FY 2017

The program office established contracts for Phase B for the new missions, Lucy and Psyche.

InSight continued testing and integration throughout FY 2017, with delivery of the SEIS instrument in July 2017.

Dawn completed its high altitude extended mission in the third quarter and initiated a highly elliptic orbit around Ceres. NASA extended the mission for an additional year, its second mission extension.

WORK IN PROGRESS IN FY 2018

NASA will launch InSight in May 2018. Lucy and Psyche will work towards their Preliminary Design Reviews (PDRs) and prepare to enter implementation upon confirmation.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

NASA will release an Announcement of Opportunity for the Discovery Program.

Program Schedule

Date	Significant Event
May 2018	InSight Launch at Vandenberg
2019	Discovery 15 Announcement of Opportunity (AO)
2021	Lucy Launch
2022	Psyche Launch

DISCOVERY

Program Management & Planned Cadence

The Discovery Program is a multiple-project program, with responsibility for implementation assigned to the Planetary Missions Program Office, located at the Marshall Space Flight Center (MSFC).

The Discovery Program has an objective to launch a flight mission an average of one every 36 months, with a goal of one every 24 months, commensurate with the availability of adequate funding. This budget provides for a mission every 30 months.

Acquisition Strategy

NASA competitively selects new Discovery missions, releasing announcements of opportunity when available funding allows.

INDEPENDENT REVIEWS

The Discovery Program's next Program Implementation Review (PIR) will occur in 2019.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PIR	SRB	Aug 2016	Review implementation of Program	Passed	2019

INSIGHT

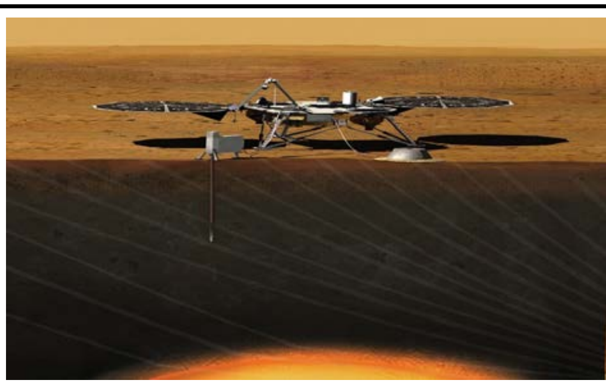
Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023	BTC	Total
Formulation	98.9	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	98.9
Development/Implementation	554.3	32.3	86.9	**0.0**	0.0	0.0	0.0	0.0	0.0	673.5
Operations/Close-out	0.0	0.0	22.5	**22.3**	11.8	0.0	0.0	0.0	0.0	56.6
2018 MPAR LCC Estimate	**653.1**	**32.3**	**109.4**	**22.3**	**11.8**	**0.0**	**0.0**	**0.0**	**0.0**	**828.9**
Total Budget	**653.1**	**32.3**	**109.4**	**22.3**	**11.8**	**9.0**	**9.0**	**9.0**	**0.0**	**855.9**
Change from FY 2018				**-87.1**						
Percentage change from FY 2018				**-79.6%**						

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



Scientists have determined the deep structure of only one planet: Earth. To obtain vital clues to how Mars formed, InSight will deploy a German-built drill nicknamed "The Mole" to pound 16 feet into the Martian crust for thermal measurements, and a sensitive French-built seismometer to detect "Marsquakes." Through these and other instruments, scientists will be able to deduce the deep structure of Mars, which currently is a mystery.

PROJECT PURPOSE

InSight is a Mars lander mission to investigate fundamental issues of terrestrial planet formation and evolution with a study of the deep interior of Mars. This mission will seek to understand the evolutionary formation of rocky planets, including Earth, by investigating the crust and core of Mars. InSight will also investigate the dynamics of any Martian tectonic activity and meteorite impacts and compare this with like phenomena on Earth.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

PROJECT PARAMETERS

NASA plans to launch InSight in May 2018, landing on Mars in November 2018. The InSight lander will be equipped with two science instruments that will conduct the first "check-up" of Mars in its more than

INSIGHT

Formulation	Development	Operations

4.5 billion years, measuring its “pulse,” or internal activity; its temperature; and its “reflexes” (the way the planet wobbles when it is pulled by the Sun and its moons). The science payload comprises two major instruments: the SEIS and the Heat Flow and Physical Properties Package (HP3). SEIS will take precise measurements of quakes and other internal activity on Mars to help understand the planet’s history and structure. HP3 is a self-penetrating heat flow probe that burrows up to five meters below the surface to measure how much heat is coming from Mars’ core. In addition, the Rotation and Interior Structure Experiment will use the spacecraft communication system to provide precise measurements of planetary rotation. InSight will spend roughly two years (720 Earth days or 700 “sols” Martian days) investigating the deep interior of Mars.

ACHIEVEMENTS IN FY 2017

NASA demonstrated the validation and qualification of a new design for the SEIS instrument and completed its development. The project delivered the instrument in July 2017 for spacecraft integration, and installed the instrument into the spacecraft in September 2017. NASA also started the Assembly, Test, Launch and Operations (ATLO) phase for the mission in July of 2017.

WORK IN PROGRESS IN FY 2018

NASA will continue with spacecraft integration and tests in the early part of FY 2018, and plans to ship the spacecraft to the launch site Vandenberg Air Force Base in February 2018, with the launch to Mars planned for May of 2018.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

The landing date for InSight is November 26, 2018, with instrument deployment starting immediately after landing. The project plans to begin science operations after instrument deployment completion (60-90 days after landing).

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2019 PB Request
Launch	Mar 2016	May 2018
Start of Prime Mission	Apr 2016	June 2018
Mars Landing	Sep 2016	Nov 2018
End of Prime Mission	Sep 2018	Nov 2020

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2014	541.8	70	2018	673.5	24.3	LRD	Mar 2016	May 2018	26

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

NASA approved a new launch date of May 2018 at the replan review in August 2016. NASA held the delta KDP-D in July 2017. The development cost details in the table below reflect the budget approved at the delta KDP-D. Total development cost has not grown since the replan review in August 2016.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**541.8**	**673.5**	**131.7**
Aircraft/Spacecraft	196.9	277.7	80.8
Payloads	18.1	80.2	62.1
Systems I&T	0.0	3.0	3.0
Launch Vehicle	159.9	167.0	7.1
Ground Systems	7.4	17.6	10.2
Science/Technology	7.1	16.0	8.9
Other Direct Project Costs	152.4	112.0	-40.4

Formulation	Development	Operations

Project Management & Commitments

NASA selected the InSight project through the competitive Discovery 2010 AO. The principal investigator for InSight is from JPL. JPL will manage the InSight mission and will provide systems engineering, safety and mission assurance, project scientists, flight dynamics, payload management, and mission system management.

Element	Description	Provider Details	Change from Baseline
Spacecraft	Similar in design to the Mars lander that the Phoenix mission used successfully in 2007	Provider: Lockheed Martin Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
SEIS	Will take precise measurements of quakes and other internal activity on Mars	Provider: CNES Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	JPL to design and develop the evacuated container for SEIS
HP3	A heat flow probe that will hammer five meters into the Martian subsurface (deeper than all previous arms, scoops, drills and probes) to measure heat emanating from the core	Provider: DLR Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Rotation and Interior Structure Experiment (RISE)	Uses the spacecraft's communication system to provide precise measurements of planetary rotation	Provider: JPL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Launch Vehicle	Atlas V launch vehicle and related launch services	Provider: United Launch Alliance (ULA) Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: Mars environment, entry conditions, or spacecraft behavior is not as anticipated, Then: Landing may not be successful.	Project will build comprehensive simulations of landing scenarios and test entry descent and landing systems, including independent verification of analysis. The project employs personnel who conducted previous successful Mars landings. The project will certify potential landing ellipses for elevation, slopes, and rock abundance. The project will use validated environmental models informed by atmospheric measurements from the previous three decades of observations at Mars.
If: Deployment of SEIS is not successful, Then: The project will not be able to meet its science objectives.	The project will conduct extensive testing of deployments in test beds, including fault scenarios. Test beds will also be available during mission operations to verify actual deployment moves, with ground verification deployed at each step during operations. The project will certify potential landing ellipses for elevation, slopes, and rock abundance.
If: SEIS develops a problem during ATLO-2, Then: Spacecraft could miss its launch date	The project has developed a spare flight unit that can replace the current flight unit in case a technical problem develops during ATLO-2.

Acquisition Strategy

NASA selected the InSight mission through a competitive Discovery Program 2010 AO and a down selection in September 2012. All major acquisitions are in place.

MAJOR CONTRACTS/AWARDS

A contract with Lockheed Martin is in place for the flight system.

Element	Vendor	Location (of work performance)
Spacecraft	Lockheed Martin	Denver, CO

INSIGHT

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Feb 2015	SIR	InSight successfully met the criteria for SIR and the PMC decision authority approved the project to continue to the next phase at KDP-D.	June 2017
Performance	SRB	June 2017	SIR-2	InSight successfully met the criteria for SIR-2 and the PMC decision authority approved the project to continue and start ATLO-2 in July 2017	Jan 2018
Performance	SRB	Jan 2018	ORR	TBD	April 2018

LUCY

Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	FY 2020	Notional FY 2021	FY 2022	FY 2023
Total Budget	**54.5**	**--**	**153.3**	**209.8**	**154.7**	**56.4**	**16.5**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Lucy will for the first time investigate Trojan asteroids, which are of particular scientific interest because they are leftovers of giant planet formation and thus provide a fossil record of the early history of the outer Solar System.

Lucy will investigate the fossils of planet formation. The mission name honors the primitive Australopithecus human fossil Lucy and the influence it has had in advancing understanding of the history of our species. The Lucy mission embodies the goal of advancing the knowledge of our planetary origin, and gaining understanding of the formation and evolution of our solar system.

The Lucy mission will investigate six primitive bodies, including one binary system (two asteroids in orbit around each other), in stable orbits near the L4 and L5 Lagrange points with Jupiter, known as the Jupiter Trojans. Scientists believe Trojans are primitive, volatile, and organic rich bodies that are gravitationally shepherded by Jupiter. Lucy is the first mission to visit the Jupiter Trojan asteroids, and NASA plans to launch it by November of 2021.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

PROJECT PRELIMINARY PARAMETERS

NASA selected the Lucy mission in December 2016 from the Discovery Program's most recent AO. Lucy, with a launch date range from October 2021 to November 2021, will reach its first Trojan in 2027, and it will have its final Trojan asteroid encounter in 2033. During its lifetime, Lucy will perform five Trojan encounters, closely studying these fascinating objects (one encounter is of a nearly equal mass binary).

LUCY

Formulation	Development	Operations

Lucy's instrument payload includes a panchromatic and color visible imager (L'Ralph), a high-resolution visible imager (L'LORRI), and a thermal infrared spectrometer (L'TES). In addition, Lucy will perform Doppler mass determinations using its radio subsystem.

Lucy will have a heliocentric trajectory and performs all its flybys in a period of 11.6 years. Lucy will fly by and extensively study several different taxonomic classes of Jupiter Trojans. A fortuitous orbital alignment that is unlikely to recur in the near future enables this comprehensive Trojans tour.

WORK IN PROGRESS IN FY 2018

Lucy will continue with project formulation and risk reduction activities throughout FY 2018.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

After completing its preliminary design review (PDR) in FY 2018, Lucy will pass its KDP-C review and enter into its final design and fabrication phase of the mission (KDP-C) in FY 2019.

ESTIMATED PROJECT SCHEDULE

All dates are preliminary.

Milestone	Formulation Authorization Document	FY 2019 PB Request
PDR	Sep 2018	Sep 2018
KDP-C	Dec 2018	Dec 2018
CDR	Oct 2019	Oct 2019
KDP-D	Aug 2020	Aug 2020
ORR	Jul 2021	Jul 2021
Launch	Oct 2021	Oct 2021- Nov 2021

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or preliminary design review.

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range

LUCY

Formulation	Development	Operations

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
Jan 4, 2017	930 - 990	Launch	Oct 2021 - Nov 2021

Project Management & Commitments

The Principal Investigator and Deputy Principal Investigator are both from the Southwest Research Institute (SwRI) in Boulder CO, and lead the management of the mission. GSFC serves as the development Center for the Lucy mission, working for the Principal Investigator. GSFC provides systems engineering; mission assurance; spacecraft design, build and test; mission and science operations; navigation; and ground data systems.

Element	Description	Provider Details	Change from Formulation Agreement
Spacecraft	Spacecraft bus and propulsion system	Provider: Lockheed Martin Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Panchromatic visible imager and IR spectrometer (L'Ralph=MVIC+ LEISA)	Provides color and near IR images to discriminate between and map compositional units.	Provider: SwRI/GSFC Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
High resolution visible imager (L'LORRI)	Provides high resolution images to determine shape, geology and albedo of the Trojans asteroids	Provider: Johns Hopkins University (JHU)/Applied Physics Laboratory (APL) Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Thermal Emission Spectrometer (L'TES)	Provides, thermal inertia maps of the Trojans elemental composition.	Provider: ASU Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Radio Science	Utilizes the X-band radio telecommunications system to measure the Trojans mass	Provider: GSFC Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

LUCY

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Navigation	Provides mission navigation design and operations.	Provider: KinetX Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

Project Risks

There are no major risks at this time.

Risk Statement	Mitigation
N/A	

Acquisition Strategy

NASA competitively selected the mission through an AO. The major elements of the mission and spacecraft are as proposed for the AO.

MAJOR CONTRACTS/AWARDS

NASA selected Lucy through the Discovery Program AO released on November 5, 2014. The Planetary Missions Program Office in Huntsville, Alabama provides programmatic oversight of the mission. The major contracts are under development.

Element	Vendor	Location (of work performance)
Spacecraft	Lockheed Martin	Denver CO
PI, Co-Is, Science data center	Southwest Research Institute (SWRI)	Boulder Co
Project management, systems engineering, SMA, spacecraft design, build and test, navigation, operations, ground data system, L'Ralph instrument	NASA GSFC	Greenbelt MD

LUCY

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Sep 2018	PDR	TBD	Oct 2019
Performance	SRB	Oct 2019	Critical Design Review (CDR)	TBD	July 2020
Performance	SRB	Jul 2020	System Integration Review (SIR)	TBD	Jul 2021
Performance	SRB	Jul 2021	Operations Readiness Review (ORR)	TBD	

PSYCHE

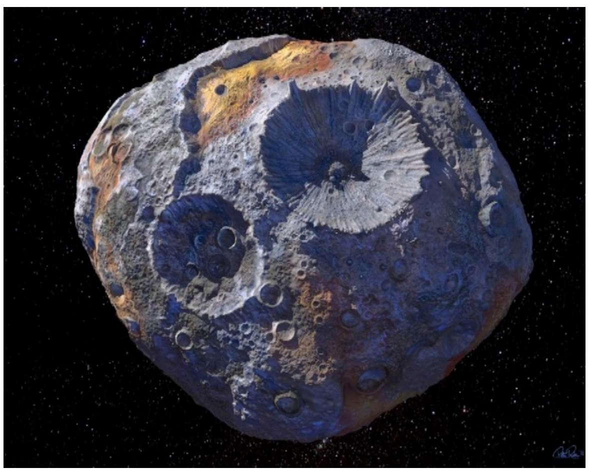
Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**47.3**	**--**	**171.2**	**214.6**	**173.3**	**163.0**	**40.1**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



Only the 16th minor planet to be discovered, hence its formal designation, 16 Psyche. At 16 Psyche, scientists will explore, for the first time ever, a world made of metal, rather than of rock or ice. It appears to be the exposed nickel-iron core of a protoplanet, one of the building blocks of the Sun's planetary system.

The Psyche mission will explore one of the most intriguing targets in the main asteroid belt—a giant metal asteroid, known as 16 Psyche, approximately three times farther away from the Sun than the Earth. This asteroid measures about 140 miles in diameter and, unlike most other asteroids that are rocky or icy bodies, is likely comprised mostly of metallic iron and nickel, similar to Earth's core. Scientists wonder whether Psyche could be an exposed core of an early planet that could have been as large as Mars, but which lost its rocky outer layers due to a number of violent collisions billions of years ago. The mission will help scientists understand how planets and other bodies separated into their layers—including cores, mantles, and crusts—early in their histories.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

PROJECT PRELIMINARY PARAMETERS

NASA plans to launch the mission in the summer of 2022 for arrival at 16 Psyche in January 2026. Psyche's instrument payload includes a multispectral imager, a gamma ray and neutron spectrometer, and a magnetometer. Psyche will use the X-band radio telecommunications system to measure 16 Psyche's gravity field.

Psyche will spend 21 months orbiting 16 Psyche in four different orbital periods. The mission will seek to aid in our understanding of iron cores. It will provide insight into terrestrial planets, including Earth, by

PSYCHE

Formulation	Development	Operations

directly examining what was once the interior of a differentiated body. In addition, it will allow us to explore a world not made of rock or ice, but of metal.

ACHIEVEMENTS IN FY 2017

Psyche continued activities to reduce mission risk and completed a thorough cost and schedule review to develop an updated budget estimate for the 2022 launch date.

WORK IN PROGRESS IN FY 2018

Psyche will continue with project formulation and risk reduction activities throughout FY 2018.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

Psyche will hold its Preliminary Design Review in March 2019 and plans to pass Key Decision Point C in May 2019.

ESTIMATED PROJECT SCHEDULE

All dates are preliminary.

Milestone	Formulation Authorization Document	FY 2019 PB Request
PDR	Mar 2019	Mar 2019
KDP-C	May 2019	May 2019
CDR	Apr 2020	Apr 2020
KDP-D	Jan 2021	Jan 2021
ORR	May 2022	May 2022
Launch	Aug 2022	Aug 2022

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or preliminary design review.

PSYCHE

Formulation	Development	Operations

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
Jan 4, 2017	907 - 957	Launch	Aug 2022

Project Management & Commitments

The Principal Investigator and Deputy Principal Investigator are both from ASU and lead the management of the mission. JPL serves as the development Center for the Psyche mission, working for the Principal Investigator. JPL provides systems engineering; mission assurance; spacecraft design, build and test; mission and science operations; navigation; and ground data systems.

Element	Description	Provider Details	Change from Formulation Agreement
Solar electric propulsion chassis	Spacecraft bus and propulsion system	Provider: Space Systems Loral Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Psyche Multispectral Imager	Provides high-resolution images using filters to discriminate between 16 Psyche's metallic and silicate constituents.	Provider: ASU Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Magnetometer	Detects and measures the remnant magnetic field of 16 Psyche.	Provider: UCLA Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Gamma Ray and Neutron Spectrometer	Detects, measures, and maps 16 Psyche's elemental composition.	Provider: APL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Gravity Science	Utilizes the X-band radio telecommunications system to measure 16 Psyche's gravity field.	Provider: Massachusetts Institute of Technology (MIT) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

PSYCHE

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Deep Space Optical Communications (DSOC)	Demonstrates DSOC technology's capabilities.	Provider: JPL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): NASA Human Exploration and Operations Mission Directorate (HEOMD)/Space Technology Mission Directorate (STMD)	N/A

Project Risks

There are no major risks at this time.

Acquisition Strategy

NASA competitively selected the mission through an Announcement of Opportunity (AO). The major elements of the mission and spacecraft are as proposed for the AO.

MAJOR CONTRACTS/AWARDS

NASA selected Psyche through the Discovery Program AO released on November 5, 2014. The Planetary Missions Program Office in Huntsville, Alabama provides programmatic oversight of the mission.

Element	Vendor	Location (of work performance)
Spacecraft	Space Systems Loral	Palo Alto CA
Project management, systems engineering, SMA, spacecraft design, build and test, navigation, operations, ground data system	JPL	Pasadena CA
PI, Co-Is, Imager, Science data center	ASU	Tempe AZ

PSYCHE

Formulation	Development	Operations

INDEPENDENT REVIEWS

All dates are preliminary.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Mar 2019	PDR	TBD	April 2020
Performance	SRB	April 2020	CDR	TBD	Dec 2020
Performance	SRB	Dec 2020	SIR	TBD	May 2022
Performance	SRB	May 2022	ORR	TBD	N/A

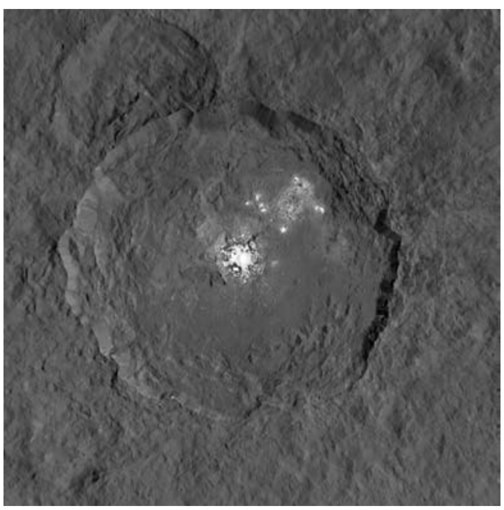
OTHER MISSIONS AND DATA ANALYSIS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Strofio	0.1	--	**0.6**	0.7	0.6	0.6	0.4
International Mission Contributions (IMC	1.9	--	**3.5**	2.4	2.2	2.0	2.0
Planetary Missions Program Office	12.2	--	**16.5**	16.5	16.5	16.5	16.5
Discovery Future	33.9	--	**5.3**	11.8	9.7	99.1	255.0
Discovery Research	11.4	--	**8.5**	9.0	9.0	9.0	9.0
Dawn	1.0	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**60.5**	**--**	**34.4**	**40.4**	**38.0**	**127.2**	**282.9**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



Enigmatic bright spots in Occator crater on the dwarf planet Ceres as seen by the Dawn spacecraft from its high-altitude mapping orbit of 915 miles (1470 kilometers). Based on the absence of other craters within it, Occator is a very recent 56-mile (90-kilometer) wide impact crater. The intense brightness of the persistent spots is due to the presence of a highly reflective material on the surface, possibly a mineral salt or pure water ice. The smooth crater floor indicates possible flowing material – either impact debris or post-impact melting or volcanism.

Other Missions and Data Analysis funds research and analysis, management activities, operations of active missions, small projects, and international collaborations. It includes missions of opportunity (e.g., the instrument Strofio; operating missions (Dawn); competed research; funding for future mission selections; and program management activities.

Mission Planning and Other Projects

STROFIO

Strofio is a unique mass spectrometer, part of the SERENA suite of instruments that will fly onboard the ESA BepiColombo spacecraft, scheduled for launch in 2018. Strofio will determine the chemical composition of Mercury’s surface, providing a powerful tool to study the planet’s geologic history.

Recent Achievements

The Strofio instrument is on board the BepiColombo spacecraft ready for launch in 2018.

OTHER MISSIONS AND DATA ANALYSIS

INTERNATIONAL MISSION CONTRIBUTIONS (IMC)

There are more scientifically interesting destinations across the solar system than any one country's program can quickly undertake. NASA works closely with the planetary science programs of other space agencies to find opportunities to participate in each other's missions. Under the International Mission Contributions, NASA funds instruments and scientific investigators, and will provide navigation and data relay services, in exchange for participation. International missions in FY 2019 include the Japanese Space Agency's Hayabusa-2 and Akatsuki (Venus Climate Orbiter) missions. The Akatsuki mission is in orbit around Venus and will investigate the planet Venus for at least the next five years. Hayabusa-2, which launched in 2014, will arrive at asteroid Ryugu in 2018 and capture and return a sample by 2020.

PLANETARY MISSIONS PROGRAM OFFICE

The Planetary Missions Program Office (PMPO) at the MSFC manages all Planetary Science flight projects that are not part of the Mars Exploration Program. This currently includes the competed Discovery and New Frontiers missions, and the JUpiter ICy moons Explorer (JUICE) and Europa projects. PMPO includes support for the day-to-day efforts of the mission managers and business office, as well as standing review boards and external technical support as needed for the projects. It also funds the Science Office for Mission Assessments (SOMA) at LaRC to support the mission selection process including the development of AOs and the formation and operations of independent panel reviews to evaluate mission proposals.

DISCOVERY FUTURE

Discovery Future funds new missions selected through the AO process, specific technology investments to enable future missions, and small missions of opportunity. NASA plans to release the next Discovery AO in 2019 with selection in 2021.

DISCOVERY RESEARCH

Discovery Research funds analysis of archived data from Discovery missions, and supports participating scientists for the, Dawn and InSight missions. Discovery Research gives the research community access to samples and data and allows research to continue for many years after mission completion. Scientists in the U.S. planetary science community submit research proposals that NASA selects through competitive peer review.

Discovery Research also funds the analysis of samples returned to the Earth by the Stardust and Genesis missions as well as the development of new analysis techniques for samples returned by future missions.

Recent Achievements

The CHILI instrument (CHicago Instrument for Laser Ionization), recently completed at the University of Chicago, performs isotopic and elemental analyses with unprecedented spatial resolution, sensitivity, and control of interferences. Researchers have demonstrated the instrument's capabilities in a variety of publications on presolar grains and meteorites, and work on samples by Discovery missions Stardust and Genesis are underway. Scientists will use the instrument in the future on samples returned by Hayabusa2 and OSIRIS-REx in coming years.

OTHER MISSIONS AND DATA ANALYSIS

One of the great benefits of sample-return missions is that the science payoff is great, but it can take many years to achieve the most challenging goals, some of which may be beyond technological capabilities at the time of the mission. The community has now reviewed the state of Stardust and Genesis science in a pair of publications (Westphal et al. 2017; Burnett and Jurewicz 2017), and outlined the highest priority science goals that remain for the future. These will guide future research solicitations. In FY 2017, eighteen peer-reviewed publications resulted from studies of these samples, including results on interstellar grains collected by Stardust, and results on the Fe and Ni content of solar wind collected by Genesis.

Operating Missions

DAWN

Dawn is completing its journey to two of the most massive, intact bodies in the main asteroid belt between Mars and Jupiter. By closely orbiting asteroid Vesta and the dwarf planet Ceres with the same set of instruments, Dawn has the unique capability to compare and contrast these bodies, enabling scientists to answer questions about the formation and evolution of the solar system. Their surfaces preserve clues to the solar system's first 10 million years, along with alterations since that time, allowing Dawn to investigate both the origin and the current state of the main asteroid belt. Launched in September 2007, Dawn reached Vesta in July 2011, left in August 2012, and arrived at Ceres in March 2015. Dawn is currently on a second extended mission period and will continue studying Ceres until the fall of 2018.

Data from the Dawn mission revealed the rugged topography and complex textures on the surface of Ceres. Additional data, such as the chemical composition, interior structure, and geologic age, are helping scientists to understand the history of the only dwarf planet of the inner solar system and the planetary evolution processes that took place in the early solar system.

Recent Achievements

Early images of Ceres revealed a heavily cratered surface and enigmatic bright spots. The mission has shown that clay-like minerals with only small areas of ice dominate the surface, which has scientists rethinking the formation and evolution history and the internal structure of this small world. The intense brightness of the persistent spots is due to the presence of highly reflective materials on the surface, which appear to be mineral salts and water ice. In 2016, Dawn completed its primary mission. NASA approved the mission to remain in orbit at Ceres for a 12-month extended mission. During the extended mission, Dawn moved to a high, elliptical orbit to obtain an improved calibration of its gamma ray and neutron detector, which provides information about the elemental composition of Ceres' surface. In October 2017, NASA approved Dawn for a second extension of a year's duration in which it will orbit Ceres in a highly elliptical orbit with a low altitude perigee.

NEW FRONTIERS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Other Missions and Data Analysis	134.0	--	**130.2**	163.7	245.0	327.6	388.4
Total Budget	**134.0**	**--**	**130.2**	**163.7**	**245.0**	**327.6**	**388.4**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

NASA's Juno spacecraft is in orbit at Jupiter where it captured this beautiful image of Jupiter's swirling clouds. Juno's primary science goal is to use science instruments to probe beneath those clouds to understand Jupiter's interior structure. Knowing the details of the interior will tell us how Jupiter formed and by extension, how planets throughout the Universe form.

The New Frontiers program explores our solar system with medium-class spacecraft missions. Within the New Frontiers program, possible mission destinations and the science goals for each competitive opportunity are limited to specific science targets announced for the competition.

The program is currently comprised of three missions in operations: New Horizons, Juno, and OSIRIS-REx.

The New Horizons mission is helping us understand worlds at the edge of the solar system. Having completed the first-ever reconnaissance of Pluto and its moons, the spacecraft is on its way to a fly-by of MU69, a small world in the Kuiper Belt.

Juno is a mission to Jupiter that is significantly improving our understanding of the origin and evolution of the gas giant planet. Juno is helping us understand the formation of planets and the origins of our solar system.

OSIRIS-REx will bring pristine samples from a carbon-rich asteroid (Bennu) to study and analyze on Earth. This will increase our understanding of the role that primitive bodies such as Bennu played in planet formation and the origin of life. In addition to its science objectives, OSIRIS-REx will improve our knowledge of how to operate human and robotic missions safely, in close proximity to a large Near-Earth Object (NEO). This knowledge will provide significant insight for potential planetary defense strategies.

Potential future missions identified by the National Academies include Venus in Situ Explorer, Saturn Probe, Trojan Tour and Rendezvous, the Comet Surface Sample Return, Lunar South Pole-Aitken Basin Sample Return, Io Observer, and Lunar Geophysical Network. NASA added, to the current New Frontiers 4 AO, Ocean Worlds targets Enceladus and Titan.

NEW FRONTIERS

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

The New Horizons mission successfully completed a set of stellar occultation observations which has aided in the trajectory development for its next Kuiper Belt target on January 2019, called MU69.

Juno successfully completed eight polar orbits (each orbit duration is 53 Earth days), achieving a significant portion of their level one science.

The OSIRIS-REx mission completed its Earth gravity assist on September 2017, and is currently in a direct trajectory to its main belt asteroid sample return target, Bennu.

WORK IN PROGRESS IN FY 2018

The New Horizons mission is developing the scientific observational sequences for its next Kuiper Belt target, called MU69. MU69 encounter phase is from mid-2018 through March 2019.

Juno is operating in a high radiation environment from pole to pole, and planning to complete their level one science in FY 2019.

The OSIRIS-REx mission is preparing for its rendezvous with Bennu. The approach phase starts in August 2018.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

NASA expects to select the next New Frontiers mission.

The New Horizons mission plans to fly-by by its next Kuiper Belt target on January 2019, called MU69, and start downlink of the data.

The Juno mission will complete its prime science and submit an extended mission request.

The OSIRIS-REx mission will start mapping while flying in tandem with Bennu in preparation for the selection of the sample location region. OSIRIS-REx will map Bennu for two years before performing its sample return collection.

NEW FRONTIERS

PROGRAM SCHEDULE

Date	Significant Event
December 2017	NF4 Step 1 Selection
April 2019	NF4 Step 2 Down-selection
2022	NF5 AO release

PROGRAM MANAGEMENT & PLANNED CADENCE

The New Frontiers Program is a multiple-project program, with responsibility for implementation assigned to the Planetary Missions Program Office, located at the Marshall Space Flight Center (MSFC). The New Frontiers Program AO cadence is approximately every 5-6 years.

ACQUISITION STRATEGY

NASA competitively selects New Frontiers missions, releasing announcements of opportunity when available funding allows.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PIR	MSFC	2016	Program Implementation Review	completed	2021

OTHER MISSIONS AND DATA ANALYSIS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
New Frontiers Future Missions	1.5	--	**30.8**	64.1	183.3	271.0	351.2
New Frontiers Research	1.7	--	**9.4**	9.4	9.4	9.4	9.5
Origins Spectral Interpretation Resource	39.5	--	**50.3**	50.7	21.6	22.2	27.7
New Horizons	29.4	--	**14.7**	14.5	5.7	0.0	0.0
Juno	61.9	--	**25.0**	25.0	25.0	25.0	0.0
Total Budget	**134.0**	**--**	**130.2**	**163.7**	**245.0**	**327.6**	**388.4**

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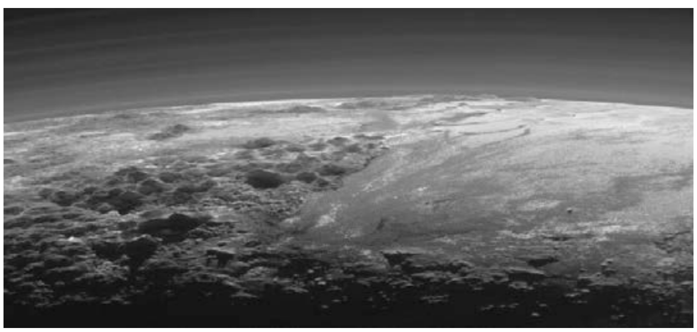

Just 15 minutes after its closest approach to Pluto on July 14, 2015, NASA's New Horizons spacecraft looked back toward the Sun and captured a near-sunset view of the rugged, icy mountains and flat ice plains extending to Pluto's horizon. Scientists think the mountains of Pluto are made of water ice, which is one of the few materials on Pluto that is strong enough at the extremely low temperatures to form the steep slopes of the huge mountains. The smooth expanse of the informally named Sputnik Planum (right) is flanked to the west (left) by rugged mountains up to 11,000 feet (3,500 meters) high, including the informally named Norgay Montes in the foreground and Hillary Montes on the skyline.

New Frontiers Other Missions and Data Analysis supports operating New Frontiers missions (New Horizons, Juno and OSIRIS-REx), analysis of data from those missions, as well as preparation for future missions.

Mission Planning and Other Projects

NEW FRONTIERS FUTURE MISSIONS

New Frontiers Future supports technology development for future missions, and provides the funding required for the next AO. NASA released the fourth New Frontiers AO in early December 2016, and expects to select a new mission in April 2019.

NEW FRONTIERS RESEARCH

New Frontiers Research funds analysis of archived data from New Frontiers missions. New Frontiers Research gives the research community access to samples and data and allows research to continue for many years after mission completion. This allows the maximum science return from each of the missions. Scientists in the U.S. planetary science community submit research proposals that NASA selects through competitive peer review. NASA will select new research in 2019, using the New Horizons mission data returned from Pluto and the Juno mission data returned from Jupiter.

Operating Missions

NEW HORIZONS

New Horizons is the first scientific investigation to obtain a close look at Pluto and its moons Charon, Nix, Hydra, Kerberos, and Styx (scientists discovered the last four moons after the spacecraft's launch in 2006). Scientists aim to find answers to basic questions about the surface properties, geology, interior makeup, and atmospheres on these bodies.

New Horizons launched on January 19, 2006. It successfully encountered Pluto in July 2015, and completed downloading all the primary science observation of the Plutonian System on October 2016. The spacecraft will next venture deeper into the Kuiper Belt, and as part of a NASA-approved extended mission, study one of the small icy bodies in this region approximately two billion miles beyond Pluto's orbit. The project has completed the maneuvers required to fly by Kuiper Belt Object 2014MU69 in January 2019.

Recent Achievements

The New Horizons project developed the Kuiper Belt Extended Mission (KEM) Integrated Master Schedule (IMS), and established the baseline in April 2017. The Student Dust Counter continues to collect unprecedented new data of an area of our Solar System little explore before.

Some of the surprising findings from Pluto by New Horizons include:

- Charon's enormous equatorial extensional tectonic belt hints at the freezing of a former water ice ocean inside Charon in the distant past. Other evidence found by New Horizons indicates Pluto could well have an internal water-ice ocean today.
- All of Pluto's moons that can be age-dated by surface craters have the same, ancient age—adding weight to the theory that they formed together in a single collision between Pluto and another body in the Kuiper Belt long ago.
- Charon's dark, red polar cap is unprecedented in the solar system and may be the result of organic atmospheric gases that escaped Pluto and then accreted on Charon's North Pole.
- Pluto's vast 1,000-kilometer-wide heart-shaped nitrogen glacier (called Sputnik Planum) that New Horizons discovered is the largest known glacier in the solar system.
- Pluto shows evidence of vast changes in atmospheric pressure and, possibly, past presence of running or standing liquid volatiles on its surface and underneath its icy crust – something only seen elsewhere on Earth, Mars and Saturn's moon Titan in our solar system.
- The New Horizons project successfully completed stellar occultations on June and July 2017 to determine that MU69 is possibly a binary object 14 to 25 miles (22 to 40 kilometers) wide. The overflight of this new world MU69 is on target for 1/1/2019. There is currently a public engagement competition to name MU69.

OTHER MISSIONS AND DATA ANALYSIS

JUNO

Juno is conducting an in-depth study of Jupiter, the most massive planet in the solar system. Juno's instruments seek information from deep in Jupiter's atmosphere, enabling scientists to understand the fundamental processes of the formation and early evolution of the solar system. Juno launched on August 5, 2011 and entered Jupiter's orbit on July 4, 2016. During its science operations mission, Juno is sampling Jupiter's full range of latitudes and longitudes. From its polar perspective, Juno combines remote sensing observations to explore the polar magnetosphere and determine what drives Jupiter's remarkable auroras. Juno has an onboard camera that is producing images and providing unique opportunities to engage the next generation of scientists.

Recent Achievements

Juno is currently in a 53-day orbit and has successfully completed nine science flybys of Jupiter. Juno's instruments have started their mapping of Jupiter's previously unknown interior structure.

Initial results indicate that limited rocky material is spread out in a diffuse, "fuzzy" deep core and that the magnetic field may have multiple origins. Deep atmospheric mapping indicates that there is a wide current of ammonia flowing up from the deeps at the equator, hinting at deep circulation patterns. The deep atmosphere below the iconic Great Red Spot is clearly warmer than the surroundings for as far down as we can see, thus hinting at the origins of the Earth-sized superstorm.

Particles creating the blazing auroral lights are being mapped back to volcanoes on Jupiter's moon Io but the mysterious, beautiful patterns in the auroral images (in the ultraviolet and infrared) are still being deciphered.

OSIRIS-REX

OSIRIS-REx will be the first U.S. mission to bring a sample from an asteroid back to Earth. The OSIRIS-REx spacecraft will travel to (101955) Bennu, a near-Earth carbonaceous asteroid formerly designated 1999 RQ36, study the asteroid in detail, and bring back a sample (at least 60 grams or 2.1 ounces) to Earth. This sample will yield insight into planet formation and the origin of life, and the data collected at the asteroid will aid in understanding asteroids that can collide with Earth. This mission will also measure the Yarkovsky effect on a potentially hazardous asteroid and measure the asteroid properties that contribute to this effect. The Yarkovsky effect is a small force on an asteroid caused by the Sun, as the asteroid absorbs sunlight and re-emits that energy as heat. The small force adds up over time, but it is uneven due to an asteroid's shape, wobble, surface composition, and rotation. For scientists to predict an Earth-approaching asteroid's path, they must understand how the effect will change its orbit. By describing the integrated global properties of a primitive carbonaceous asteroid, this mission will allow for direct comparison with ground- based telescopic data of the entire asteroid population.

OSIRIS-REx launched on September 8, 2016 and flew by the Earth on September 22, 2017. After almost two years in space, OSIRIS-REx will approach Bennu, arriving close enough to begin observations in August 2018. The mission will study the asteroid for about one year, globally mapping the surface from distances of about three miles to less than half a mile. The spacecraft cameras and instruments will photograph the asteroid and measure its surface topography, composition, and thermal emissions. Radio science will provide mass and gravity field maps. This information will help the mission team select the most promising location to collect a sample of pristine asteroid material. In 2020, the spacecraft will descend to the surface of the asteroid, and gently contact the surface, collecting a sample, before backing away. The spacecraft will remain near the asteroid for almost another two years before beginning its return to Earth. To deliver the sample to Earth, OSIRIS-REx has a capsule similar to the one that returned the sample of Comet 81P/Wild on the Stardust spacecraft. The capsule with its pristine sample from Bennu will land at the Utah Test and Training Range on September 24, 2023. NASA will transport the capsule containing the sample to JSC for processing, analysis, and curation at a dedicated research facility. JSC will make subsamples available for research to the worldwide science community.

Recent Achievements

In February 2017, OSIRIS-REx conducted a search for asteroids near one of the Earth Trojan points, exercising the observations and analysis planned for asteroid approach to search for small satellites that might be orbiting Bennu. OSIRIS-REx flew by the Earth on September 22, 2017, receiving a gravity assist to change the plane of its orbit to match the orbit of its target asteroid, Bennu. OSIRIS-REx took advantage of this flyby to obtain calibration observations of the Earth and Moon.

MARS EXPLORATION

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	FY 2020	Notional FY 2021	FY 2022	FY 2023
Mars Rover 2020	408.0	374.3	**348.0**	296.9	154.8	133.0	60.4
Other Missions and Data Analysis	239.0	--	**253.5**	232.7	217.1	157.8	154.9
Total Budget	**647.0**	**--**	**601.5**	**529.7**	**371.9**	**290.8**	**215.3**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

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Every time we feel close to understanding Mars, new discoveries send us straight back to the drawing board to revise existing theories. We've discovered that today's Martian wasteland hints at a formerly volatile world where volcanoes once raged, meteors plowed deep craters, and flash floods rushed over the land, and yet we now know that early Mars could have supported microbial life. Mars continues to throw out new enticements with each landing or orbital pass made by our spacecraft.

The Mars Exploration Program seeks to understand when Mars was habitable, is Mars habitable today, or can it be a habitable world in the future, and whether it ever supported life. As the most Earth-like planet in the solar system, Mars has a landmass approximately equivalent to the Earth's as well as many of the same geological features, such as riverbeds, past river deltas, and volcanoes. Mars also has many of the same "systems" that characterize Earth, such as air, water, ice, and geology that all interact to produce the Martian environment. Mars also has fundamental differences from Earth including the lack of a global magnetic field and chaotic changes in the orientation of its spin axis over tens of millions of years, which have affected its environment.

The four broad, overarching goals for Mars Exploration are to:

- Determine if life ever arose on Mars:
- Characterize the climate of Mars;
- Characterize the geology of Mars; and
- Prepare for human exploration.

Today, our robotic scientific explorers are paving the way. Together, humans and robots will pioneer Mars and the solar system.

MARS EXPLORATION

EXPLANATION OF MAJOR CHANGES IN FY 2019

This Budget, through funding in the Mars Future project, supports studies and technology development in support of a Mars Sample Return mission. In developing concepts for a Mars Sample Return mission, NASA intends to leverage commercial and other partnerships.

The MER mission has been extended through FY 2019 and the Odyssey mission has been extended from FY 2019 through FY 2022.

MARS ROVER 2020

Formulation	Development	Operations

FY 2019 Budget

		Actual	CR	Request	Notional					
Budget Authority (in $ millions)	Prior	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	BTC	Total
Formulation	393.1	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	393.1
Development/Implementation	227.3	425.2	400.9	**355.4**	277.6	1.1	0.0	0.0	0.0	1687.6
Operations/Close-out	0.0	0.0	0.0	**0.0**	23.4	157.6	134.8	61.7	0.0	377.5
2017 MPAR LCC Estimate	**620.4**	**425.2**	**400.9**	**355.4**	**301.1**	**158.7**	**134.8**	**61.7**	**0.0**	**2458.2**
Total Budget	**575.1**	**408.0**	**347.3**	**348.0**	**296.9**	**154.8**	**133.0**	**60.4**	**0**	**2350.5**
Change from FY 2018				**-45.5**						
Percentage change from FY 2018				**-11.3%**						
Total NASA Budget	**620.4**	**425.2**	**400.9**	**355.4**	**301.1**	**158.7**	**134.8**	**61.7**	**0.0**	**2458.2**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

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The MPAR LCC estimate is higher than the Total Budget because it includes contributions from other Mission Directorates. Total Budget reflects the total SMD budget.

Mars 2020 will re-use the basic engineering of NASA's Mars Science Laboratory to send a different rover to Mars, with new objectives and instruments, launching in 2020. The rover will carry seven instruments to conduct its science and exploration technology investigations including two contributed by international partners and one to demonstrate a critical technology for future human exploration.

PROJECT PURPOSE

The Mars 2020 science rover is a mission, currently in development, that will advance the scientific priorities detailed in the National Research Council’s Planetary Science Decadal Survey, entitled “Vision and Voyages for Planetary Science in the Decade 2013-2022.” In addition, the mission provides an opportunity for payload elements provided by the HEOMD and the STMD that align with their priorities and are compatible with SMD priorities.

NASA’s Mars 2020 mission will build upon many discoveries from the Mars Curiosity rover and the two Mars Exploration Rovers, Spirit and Opportunity, by taking the next key steps in our understanding of Mars’ potential as a habitat for past or present life. The Mars 2020 rover will seek signs of past life on

MARS ROVER 2020

Formulation	Development	Operations

Mars, collect and store a set of samples for potential return to Earth in the future, and test new technology to benefit future robotic and human exploration of Mars. The mission will also deploy new capabilities developed through investments by NASA's Space Technology Mission Directorate, Human Exploration and Operations Mission Directorate, and contributions from international partners.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

PROJECT PARAMETERS

The Mars 2020 mission is planned to launch in July 2020, landing on Mars in February 2021, and spending at least one Mars year (two Earth years) exploring the landing site region. The mission uses much of the design of the highly successful Mars Science Laboratory (MSL) “Curiosity” rover, which has been exploring Mars since 2012. The Mars 2020 rover body and other major hardware (such as the cruise stage, aeroshell, and heat shield) will be near-duplicates of the systems of MSL and will take maximum advantage of engineering heritage. The new rover will carry more sophisticated, upgraded hardware and new instruments to conduct geological assessments of the rover's landing site, determine the potential habitability of the environment, and directly search for signs of ancient Martian life. To minimize costs and risks, NASA will use a proven landing system and rover chassis design as much as possible, while still delivering a highly capable rover.

The Mars 2020 rover is carrying a competitively selected science and technology instrument payload of seven instruments. NASA chose five of those instruments to provide the clearest possible measurements for seeking possible signs of ancient life (potential “biosignatures”) on Mars over its long, 4.6 billion-year history. NASA chose the remaining two instruments to assess environmental hazards and resources for future human exploration. The rover also will collect and store samples of rocks and soils in sealed tubes, which will be stored on the surface of Mars for possible return to Earth by a subsequent mission. NASA is exploring a range of potential options to return these cached samples to Earth, including a future NASA Science or NASA-sponsored mission, or via a commercial or international partnership. We are exploring opportunities to partner with industry to leverage their future missions to advance decadal survey science objectives.

The rover’s baseline power source is a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG). It uses the heat from the natural decay of plutonium-238 to generate electricity. NASA and ESA telecommunications relay assets in Mars orbit will support the mission.

ACHIEVEMENTS IN FY 2017

The Mars 2020 mission completed its Critical Design Review (CDR) and continued design and fabrication.

MARS ROVER 2020

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2018

The Mars 2020 mission will complete the System Integration Review (SIR) and begin Assembly, Test, and Launch Operations (ATLO).

KEY ACHIEVEMENTS PLANNED FOR FY 2019

The Mars 2020 mission will deliver the instrument payload to spacecraft assembly, test, and launch operations (ATLO).

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2019 PB Request
KDP-C	Jun 2016	Jun 2016
CDR	Dec 2016	Feb 2017
KDP-D	Jan 2018	Apr 2018
Launch Readiness Date	Jul 2020	Jul 2020
Landing	Feb 2021	Feb 2021
End of Prime Mission	Jun 2023	Jun 2023

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2017	SMD 1620.1 NASA 1676.9	70	2018	SMD 1620.1 NASA 1687.6	0.6	LRD	Jul 2020	Jul 2020	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

MARS ROVER 2020

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**1676.9**	**1687.6**	**10.7**
Technology Development	88.4	135.6	47.2
Aircraft/Spacecraft	527.4	685.4	158.0
Payloads	155.4	199.5	44.1
Systems I&T	71.1	71.1	0
Launch Vehicle/Services	342.5	239.5	-103.0
Ground Systems	80.4	98.8	18.4
Science Technology	16.5	20.3	3.8
Other Direct Project Costs	395.1	237.4	-157.8

MARS ROVER 2020

Formulation	Development	Operations

Project Management & Commitments

The Jet Propulsion Laboratory has project management responsibility for Mars 2020.

Element	Description	Provider Details	Change from Baseline
Mastcam-Z	Advanced camera system with panoramic and stereoscopic imaging capability with the ability to zoom	Provider: ASU Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	None
SuperCam	Instrument that can provide imaging, chemical composition analysis, and mineralogy	Provider: Los Alamos National Laboratory Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): CNES	None
PIXL	An X-ray fluorescence spectrometer that will also contain an imager with high resolution to determine the fine scale elemental composition of Martian surface materials	Provider: JPL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	None
SHERLOC	A spectrometer that will provide fine-scale imaging and uses an ultraviolet (UV) laser to determine fine-scale mineralogy and detect organic compounds.	Provider: JPL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	None
RIMFAX	A ground-penetrating radar that will provide centimeter-scale resolution of the geologic structure of the subsurface	Provider: Norwegian Defense Research Establishment, Norway Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): NASA SMD	None
MEDA	A set of sensors that will provide measurements of temperature, wind speed and direction, pressure, relative humidity and dust size and shape	Provider: Centro de Astrobiologia, Instituto Nacional de Tecnica Aeroespacial, Spain Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): NASA HEOMD/STMD	None

MARS ROVER 2020

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
MOXIE	An exploration technology investigation that will produce oxygen from Martian atmospheric carbon dioxide	Provider: Massachusetts Institute of Technology Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): HEOMD/STMD	None
MEDLI-2	A set of engineering sensors embedded in the aeroshell to gather data on the aerothermal conditions, thermal protection system, and aerodynamic performance during atmospheric entry and descent.	Provider: NASA Langley Research Center (LaRC) Lead Center: LaRC Performing Center(s): LaRC/JPL Cost Share Partner(s): HEOMD/STMD	None

Project Risks

Risk Statement	Mitigation
If: SHERLOC has significant implementation issues (technical, schedule, or cost) due to the large number of new and challenging subassemblies (laser, laser power supply, scan mirror, etc.), Then: Direct development cost (instrument side) and project ripple effects (flight system thermal/mechanical/ATLO) and schedule impacts could result.	The project initiated a schedule optimization process with focus on the engineering model delivery schedule. Additional resources and institutional support provided to address key risk areas. The project aggressively mitigated subassembly level risks at the component and subassembly level and continually develops further subsystem level schedule mitigations.
If: Planned supersonic parachute development and risk reduction testing are not successful in addressing parachute inflation survivability concerns, Then: Additional development cycles and test campaigns may be required and could consume all available project schedule margin.	Assess the outcome of planned supersonic parachute development and risk reduction testing. Investigate long lead needs for both additional parachute development and testing.

MARS ROVER 2020

Formulation	Development	Operations

Risk Statement	Mitigation
If: One or several of the aggregated EDL residual risks or unknown-unknowns that are inherited from MSL is realized (such as single point failures, environmental factors), Then: Could cause loss of mission.	Risk updated to remove risks retired by MSL's flight itself and Mars 2020 plans that will correct some testing shortfalls. Previously 43 identified risks; reduced to 27. Reexamine aggregated risks to understand if any baseline changes affect them. It is very likely that the Mars 2020 mission will need to accept most, if not all, of the aggregated residual risks. Engineers have brought identified mitigations forward for approval as part of the flight software scrub.
If: Complexity of the Sampling and Caching Subsystem (SCS) drives delays in development/test activities, or new actuators are late being delivered by the Motion Control Subsystem (MCS), or new or modified contamination control requirements require additional time to complete assembly/test, or additional re-design cycles of SCS hardware delays build/testing, Then: The delivery of the Sampling and Caching System (SCS) hardware to ATLO may be later than planned.	The Flight System has worked with the Project and the SCS and MCS subsystems to do the following: Mostly retired initial design and fabrication risk. Focus is on end-effector and bit carousel. Engineering development unit delivered to SCS testbed for use in risk reduction. Developed a plan to ensure engineering development and test effectively influences flight hardware while minimizing the impact to delivery dates. Finalized end-effector design and actuator selection, allowing closure of performance requirements; finalized vendors and designs for all new actuators required for SCS; finalized rover motor controller design relative to actuators; reduced complexity by removing tube warming station and adding T-0 purge to the SCS caching assembly. MCS actuator development detailed design reviews and SCS critical design review are complete; SCS is moving into fabrication, assembly, and test.

MARS ROVER 2020

Formulation	Development	Operations

Acquisition Strategy

NASA is acquiring the spacecraft and flight systems for the Mars 2020 mission through JPL and the radioisotope power system through the Department of Energy, taking advantage of the previous investment in the MSL project to maximize heritage. By using contracts existing from the MSL project to procure new versions of the as-flown hardware, JPL plans to maintain the lowest possible costs. NASA competitively selected the Mars 2020 investigations payload.

MAJOR CONTRACTS/AWARDS

NASA released an announcement of opportunity for the Mars 2020 rover instruments on September 24, 2013, with selections announced on July 31, 2014. NASA selected seven science instruments and exploration technology investigations for the Mars Rover 2020 payload.

Element	Vendor	Location (of work performance)
Aeroshell	Lockheed Martin	Denver, CO
Actuators	Cobham	Hauppauge, NY
Robotic arm	Motiv	Pasadena, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Oct 2014 / Mar 2015	SRR & MDR	Mars 2020 successfully met the criteria and the PMC decision authority approved the project to continue to the next phase.	Feb 2016
Performance	SRB	Feb 2016	PDR	Complete	Feb/Mar 2017
Performance	SRB	Feb/Mar 2017	CDR	Complete	Feb/Mar 2018
Performance	SRB	Feb/Mar 2018	SIR	TBD	May 2020

MARS ROVER 2020

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	May 2020	ORR	TBD	

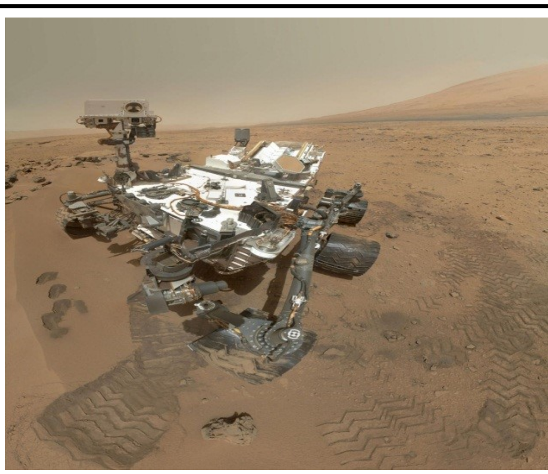
OTHER MISSIONS AND DATA ANALYSIS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Mars Organic Molecule Analyzer (MOMA)	12.1	--	**8.5**	6.7	6.9	6.0	6.0
Aeroscience Ground Test Capabilities	14.6	--	**21.5**	22.2	22.2	22.2	22.2
ExoMars	2.2	--	**2.3**	2.1	2.2	0.0	0.0
Mars Program Management	24.2	--	**19.8**	19.8	20.0	13.7	15.3
Mars Future Missions	20.0	--	**50.0**	50.0	50.0	50.0	50.0
Mars Mission Operations	1.9	--	**1.9**	1.9	1.9	1.9	1.9
Mars Research and Analysis	10.0	--	**10.0**	10.0	10.0	10.0	10.0
Mars Technology	22.9	--	**8.5**	4.0	4.5	4.5	4.5
2011 Mars Science Lab	56.2	--	**54.0**	54.0	50.0	0.0	0.0
Mars Reconnaissance Orbiter 2005 (MRO)	28.0	--	**27.0**	27.0	26.0	26.0	25.0
Mars Exploration Rover 2003	12.5	--	**12.0**	0.0	0.0	0.0	0.0
Mars Odyssey 2001	10.8	--	**11.5**	11.5	0.0	0.0	0.0
Mars Express	3.0	--	**3.0**	0.0	0.0	0.0	0.0
Mars Atmosphere & Volatile EvolutioN	20.5	--	**23.5**	23.5	23.5	23.5	20.0
Total Budget	**239.0**	**--**	**253.5**	**232.7**	**217.1**	**157.8**	**154.9**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



Rigorous scientific questions will drive all of our future missions. The questions will continuously evolve as we make new discoveries. Brand new technologies will enable us to explore Mars in ways we never have before, resulting in higher-resolution images, precision landings, longer-ranging surface mobility, and the ability to cache samples.

Other Missions and Data Analysis includes the mission planning and other projects such as NASA's contribution (MOMA) to the European Space Agency ExoMars 2020 rover, Aeroscience Ground Test Capabilities, ExoMars, Mars Program Management, Mars Mission Operations, Mars Research and Analysis, Mars Technology, and Mars Future. In addition to the mission planning projects are the operating projects which include Mars Science Laboratory (MSL), Mars Reconnaissance Orbiter 2005 (MRO), Mars Exploration Rover 2003 (MER,) Mars Odyssey 2001, Mars Express, and Mars Atmosphere and Volatile Evolution (MAVEN). Also included are the flight operations, NASA-contributed Electra communications radios, and the participation of co-Investigators on two instruments of the 2016 Exobiology on Mars (ExoMars) Trace Gas Orbiter (TGO).

OTHER MISSIONS AND DATA ANALYSIS

Mission Planning and Other Projects

MARS ORGANIC MOLECULE ANALYZER (MOMA)

MOMA is the core astrobiology instrument on the ESA ExoMars 2020 rover, and it addresses the top ExoMars science goal of seeking signs of past or present life on Mars. The MOMA-MS is the NASA-provided subsystem of MOMA, which is in development. It is primarily a dual-source mass spectrometer, including laser desorption capability, to detect a wide range of organic molecules in Martian samples. Organic structure and distribution can be indicators of past or present life.

AEROSCIENCE GROUND TEST CAPABILITIES

NASA established the Aeroscience Ground Test Capabilities project to help sustain the Agency's entry, descent, and landing test capabilities. This budget consists of SMD's contribution to this agency-wide effort to maintain capabilities, to ensure they are available when needed for specific missions, including Mars.

EXOMARS

The ExoMars program is a series of two missions designed to understand if life ever existed on Mars. The first mission in the ExoMars program is the 2016 TGO. For this mission, NASA contributed two Electra telecommunication radios, identical to those used successfully on NASA's MRO and MAVEN. Electra acts as a communications relay and navigation aid for Mars spacecraft. Electra's ultra-high frequency

(UHF) radios support navigation, command, and data-return needs. Furthermore, two instruments have significant contributions from US co-Investigators.

RECENT ACHIEVEMENTS

The ExoMars trace gas orbiter entered Mars orbit in late October of 2016 and the spacecraft is now aerobraking towards achieving the science orbit in April of 2018.

MARS PROGRAM MANAGEMENT

Mars Program Management provides for the broad-based implementation and programmatic management of the Mars Exploration program. Mars Program Management also supports independent panel reviews, studies regarding planetary protection, advanced mission studies and program architecture, program science, and telecommunications coordination and integration.

MARS MISSION OPERATIONS

Mars Mission Operations provides management and leadership for the development and operation of Mars multi-mission systems for operations. Mars Mission Operations supports and provides common operational systems and capabilities at a lower cost and risk than having each Mars project produce systems individually.

MARS RESEARCH AND ANALYSIS (R&A)

Mars R&A provides funding for research and analysis of Mars mission data in order to understand how geologic, climatic, and other processes have worked to shape Mars and its environment over time, as well as how they interact today. Specific investments include:

- Mars Data Analysis, which analyzes archived data collected on Mars missions; and
- Critical Data Products, which provide data and analyses for the safe arrival, aero-maneuver, entry, descent, and landing at Mars.

Data analysis through Mars R&A enables a much broader and objective analysis of the data and samples. It also allows research to continue for many years after the mission completion. These research projects increase our scientific understanding of Mars’ past and present environments, disseminating the results through the scientific publications. By using data collected by spacecraft, researchers are able to make scientific discoveries and test hypotheses about the Martian environment.

Recent Achievements

Recently published papers have provided significant new information on the water cycle of Mars, the nature and formation mechanisms of active wind-driven deposits, and the potential habitability of Mars. One of these papers concludes that hydrothermal deposits are present on Mars (a potential site for the origin of life). In addition, additional research has opened the debate about whether liquid water is the cause of recurring slope lineae on Mars.

OTHER MISSIONS AND DATA ANALYSIS

MARS TECHNOLOGY

Mars Technology focuses on technological investments that lay the groundwork for successful future Mars missions, such as entry, descent, and landing capabilities; Mars ascent vehicle components, sample handling and processing technologies; and surface-to-orbit communications improvements.

MARS FUTURE

Mars Future Missions funds the planning of future robotic missions to Mars that build on scientific discoveries from past missions and incorporate the lessons learned from previous missions. Mars Future supports study and technology development for a potential Mars Sample Return mission. In developing concepts for a Mars Sample Return mission, NASA intends to leverage commercial and other partnerships.

Operating Missions

2011 MARS SCIENCE LAB (MSL)

MSL and its Curiosity rover, which successfully landed in August 2012, completed its prime mission exploration activities. The Curiosity rover is exploring and quantitatively assessing regions on Mars as potential past habitats for life, and has determined that Mars, at least at one point in time, was once able to support microbial life. Curiosity is twice as long and three times as heavy as the Mars Exploration Rover Opportunity. The Curiosity rover is collecting Martian soil and rock samples and analyzing them for organic compounds and environmental conditions that could have supported microbial life, and making measurements of the Martian atmosphere, the radiation environment, and the weather. MSL is the first planetary mission to use precision landing techniques, steering itself toward the Martian surface. This landing method enabled the rover to land in an area less than 12 miles in diameter, about one-sixth the size of previous landing zones on Mars, and this successful system is the basis of the system architecture of the Mars 2020 mission. In addition, Curiosity is the first planetary rover to make use of a nuclear power source, which gave the rover the ability to travel up to 12 miles during the two-year primary mission. This international partnership mission uses components provided by the space agencies of Russia, Spain, and Canada.

Recent Achievements

Curiosity has traveled over 11 miles and has been exploring the lower reaches of Mt. Sharp – the prime science target of the mission and is now in its second extended mission. Scientists can attribute mineral-filled veins in multiple locations with varying mineral assemblages (starting at the base and going up Mt. Sharp) to multiple generations of water at the surface, extending both the extent and to younger times that the environment could have supported microbial life. Also accomplished are the first crystallographic and chemical ground truth of clays identified from orbit, the first characterization of the radiation environment on the surface of another planet, and the first study of an extraterrestrial active dune field.

OTHER MISSIONS AND DATA ANALYSIS

MARS RECONNAISSANCE ORBITER 2005 (MRO)

MRO, currently in its fourth extended operations phase, carries HiRISE, the most powerful camera ever flown on a planetary exploration mission. This capability provides a more detailed view of the geology and structure of Mars, and helps identify obstacles that could jeopardize the safety of future landers and rovers. MRO also carries a radar sounder to find subsurface water, an important consideration in selecting scientifically worthy landing sites for future exploration. A second camera acquires medium-resolution images that provide a broader geological context for more detailed observations from higher-resolution instruments; it has covered most of the planet and searches for new phenomena, such as new impact craters, revealing ice. In addition, MRO carries a high resolution imaging spectrometer, the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM), which can map minerals at unprecedented spatial resolution. A wide-angle camera provides daily global weather maps and an atmospheric sounder shows how the Martian atmosphere transports dust and water ice. MRO will follow up on recent discoveries of an increasingly diverse array of ancient aqueous environments and enough buried carbon dioxide ice that, if released, would double the present atmospheric pressure. In the final years of its fourth extended mission, MRO will extend mapping of the three dimensional structure and content of the polar ice deposits, characterize the episodic nature of great dust storms, expand coverage of surface changes, and monitor possible seasonal surface color changes suggestive of liquid water flow on Mars today. MRO is characterizing landing sites for the 2018 Insight Lander, Mars 2020 Rover, and the 2020 ESA ExoMars Rover. It continues a survey of possible landing sites for potential human missions. As it explores, MRO also serves as a major installment of an “interplanetary Internet,” as a relay communications orbiter relaying commands to and data from surface assets to Earth.

In FY 2018, the Mars Reconnaissance Orbiter will focus on the detection of modern surface changes and on extending surveys for the detection of aqueous minerals that indicate water-related environments (ground water, paleolakes, and possible ocean) on early Mars. In FY 2019 MRO will characterize activity during the upcoming great dust storm season on Mars. Programmatically, MRO will observe the landing of the InSight spacecraft in November 2018, while continuing to provide relay for all landed missions.

Recent Achievements

The Mars Reconnaissance Orbiter (MRO) had several significant accomplishments during FY 2017, both scientifically and programmatically. Scientifically, the mission found evidence that liquid water carved a network of valleys between paleolakes relatively late in Mars history; that extensive ice deposits from the last glacial age remain in the subsurface today; and that seasonally subliming carbon dioxide ice is responsible for many new surface changes seen in the polar regions. Characterization continues of the enigmatic Recurring Slope Lineae, which are possible brine flows on modern Mars. Programmatically, MRO has completed acquisition of the key data needed to characterize and certify the candidate landing sites for the InSight and 2020 Mars Rover missions, while continuing to provide relay for the ongoing Curiosity and Opportunity rovers.

MARS EXPLORATION ROVER 2003

For over 14 years, the Mars Exploration Rover Opportunity has explored geological settings on the surface of Mars. It has expanded understanding of the history and the geological processes that shaped Mars, particularly those involving water. Opportunity has trekked 27.9 miles across the Martian surface, (continually breaking the distance record for traverse on a planetary body beyond Earth, well over a marathon), conducting field geology, making atmospheric observations, finding evidence of ancient

OTHER MISSIONS AND DATA ANALYSIS

Martian environments where intermittently wet and habitable conditions existed, and sending back to Earth well over 223,000 spectacular, high-resolution images.

Recent Achievements

Opportunity has begun an extensive campaign to explore the clays identified by MRO's CRISM from orbit. The rover is in the process of surviving its eighth Martian winter on the south facing slopes of Perseverance Valley, maximizing its solar panel exposure as it continues exploring the most ancient terrain explored to date. This includes an ongoing investigation of the geology of a water-carved gulley, located in Endeavour Crater, for the first time from the surface.

MARS ODYSSEY 2001

Mars Odyssey, currently in its seventh extended mission operations phase, is still in orbit around Mars. It continues to send information to Earth about Martian geology, climate, and mineralogy. Measurements by Odyssey enabled scientists to create maps of minerals and chemical elements and identify regions with buried water ice. Images that measure the surface temperature provided spectacular views of Martian topography. Mars Odyssey will continue critical long-term longitudinal studies of the Martian climate. Odyssey has served as the primary means of communications for NASA Mars surface explorers over the past decade, and continues that role for the Opportunity and Curiosity rovers.

In future years, Mars Odyssey will observe the moons of Mars, providing the first-ever thermal infrared imaging of the surface under different illumination conditions, to provide evidence of the surface compositions. This will test the two opposing hypotheses for the origins of these moons: Captured asteroids or formation in orbit from impact debris.

Recent Achievements

The Mars Odyssey orbiter detected high-energy particles encountering Mars during the passage of a solar storm and observed atmospheric phenomena (hazes, clouds, fog, and frost) in the early morning and late evening hours not viewed systematically by other orbiters.

MARS EXPRESS

Mars Express, currently in its sixth extended mission operations phase, is an ESA mission that provides an understanding of Mars as a "coupled" system: from the ionosphere and atmosphere down to the surface and sub-surface. This mission addresses the climatic and geological evolution of Mars as well as the potential for life on the planet. NASA contributed components for the Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) and Analyzer of Space Plasmas and Energetic Atoms (ASPERA) instruments aboard Mars Express, and participates in the scientific analysis of mission data.

Recent Achievements

Mars Express has been performing an ongoing series of tests between the spacecraft and the Opportunity and Curiosity rovers to demonstrate and evaluate proximity radio links between orbiting and surface assets.

OTHER MISSIONS AND DATA ANALYSIS

MARS ATMOSPHERE AND VOLATILE EVOLUTION (MAVEN)

MAVEN, successfully launched in 2013, is providing a comprehensive picture of the Mars upper atmosphere, ionosphere, solar energetic drivers, and atmospheric losses, to determine how the Mars atmosphere evolved through time. The mission is answering long-standing questions regarding the loss of the Mars atmosphere, climate history, liquid water, and habitability. MAVEN is the first mission devoted to studying Mars' upper atmosphere, with the most comprehensive measurements ever taken to address key scientific questions about Mars’ evolution. It is exploring the upper atmosphere, ionosphere, interactions with the Sun and solar wind, and the resulting loss of gas from the atmosphere to space. Scientists are using MAVEN data to determine the role that loss of volatile compounds (such as carbon dioxide and water) from the Mars atmosphere to space has played through time, and the importance of this loss in changing the Mars atmosphere and climate through time. As with all Mars Exploration Program orbiters, MAVEN also carries an Electra radio for communications with rovers and landers on the Mars surface. NASA prepared MAVEN to provide contingency relay support during its primary science mission and it is evolving into a more regular communications role.

After successfully completing its primary mission in Nov 2015, MAVEN completed its first extended mission (EM-1) in Sep 2016, and is now executing its second extended mission (EM-2) with an expanded suite of science objectives and observational techniques.

Recent Achievements

MAVEN science results in FY 2017 include the first in situ detection of persistent metal ions in Mars’ upper atmosphere from the influx of interplanetary dust and measurements showing that magnetic fields in Mars’ crust affect the distant boundary of the Mars-solar wind interaction. A pivotal conclusion from MAVEN’s measurements of Argon isotopes is that the majority of Mars’ atmospheric gas was lost to space. MAVEN had its most significant opportunity thus far to study atmospheric loss processes when, on September 12, 2017, a coronal mass ejection from the Sun hit the Martian atmosphere and lit it up in a global ultraviolet aurora that was 25 times brighter than any previously seen by MAVEN. The MAVEN team uses measurements of events like this to infer how such storms may have stripped away so much of the Martian atmosphere over time, a primary mission objective. In FY 2018, the MAVEN team will continue this investigation of Mars’ atmospheric loss over time while planning for science operations from a future modified orbit that will support relay communications for new and existing surface assets at Mars.

OUTER PLANETS AND OCEAN WORLDS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Europa Clipper	275.0	--	**264.7**	200.2	359.5	358.9	361.0
Other Missions and Data Analysis	84.5	--	**20.9**	13.6	13.8	13.6	14.5
Total Budget	**359.5**	**--**	**285.6**	**213.8**	**373.3**	**372.5**	**375.5**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Europa, with its probable vast subsurface ocean sandwiched between a potentially active silicate interior and a highly dynamic surface ice shell, offers one of the most promising extraterrestrial habitable environments, and a plausible model for habitable environments beyond our solar system - Vision and Voyages for Planetary Science in the Decade 2013-2022.

The Outer Planets and Ocean Worlds program enables the exploration of worlds in our solar system possessing vast expanses of liquids, just as Earth does. These liquid reservoirs, most notably those composed of liquid water, provide insight into some of the most fundamental questions about life and the evolution of the solar system. The exploration of ocean worlds has the highest relevance and potential in the search for extant life and its habitable environments beyond Earth, one of NASA's strategic objectives.

NASA missions have revealed an increasing number of ocean worlds in our solar system while at the same time providing enticing though limited details about these unexpected oceans. Not far underneath its icy crust, Europa contains a global liquid water ocean twice as large as Earth's oceans. Recent observations suggest active plumes emanating from the surface of Europa, possibly bringing an ocean sample within easier reach. Scientists detected a similar though smaller global ocean on Enceladus, a small moon orbiting Saturn, also emanating active plumes. Other moons (such as Ganymede, Callisto, and Titan) have been shown to possess perched oceans deep beneath their surfaces, and Titan has also been shown to possess huge lakes of liquid methane on its surface – the only place beyond Earth with lakes exposed to an atmosphere.

Simultaneously with these discoveries, astrobiology research along with the exploration of Earth's oceans have demonstrated the pervasiveness of life given the proper conditions and environment. Research has increasingly indicated that ocean worlds possess at least some of the conditions necessary for extant life: long-lived oceans providing liquid water and a stable habitat, hydrothermal activity providing energy, and organics providing the necessary materials, among others. Thus, ocean worlds are the most likely places to search for currently habitable environments in the solar system and the life forms that could exist in those environments.

OUTER PLANETS AND OCEAN WORLDS

The Outer Planets and Ocean Worlds program enables science investigations spanning the diversity of worlds hosting large liquid bodies in the outer solar system. The strategic missions currently in this portfolio investigate a broad array of science disciplines with more depth than is possible for smaller, tightly focused missions in the Discovery and New Frontiers programs. These missions in turn enable the definition of focused questions that smaller missions in the Discovery and New Frontiers programs can pursue.

EXPLANATION OF MAJOR CHANGES IN FY 2019

This budget enables a Europa Clipper launch readiness date in 2025. The Administration proposes to launch the Clipper on a commercial launch vehicle, which would be several hundreds of millions of dollars cheaper than an SLS flight and would not impact the availability of SLS rockets to support human exploration. The Administration recognizes the benefits of using an SLS vehicle, including a shorter cruise to Europa and a more direct trajectory (enabling a simpler thermal design and earlier science return to inform future outer planet missions), but makes this proposal primarily due to budget considerations.

EUROPA CLIPPER

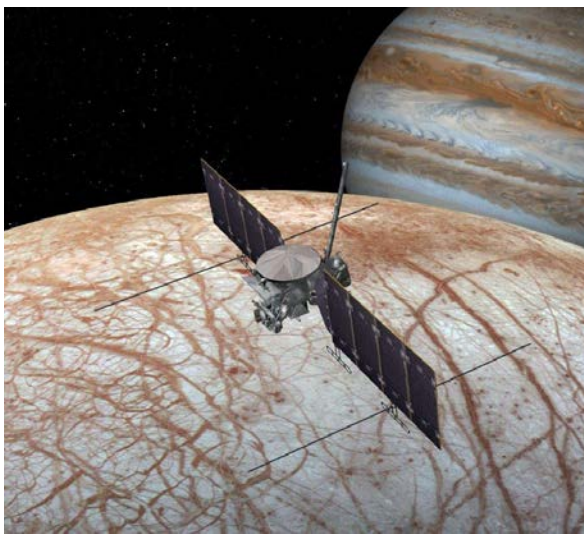
Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	237.4	--	264.7	200.2	359.5	358.9	361.0

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



NASA designed the Europa Clipper spacecraft to collect data with four in situ and five remote sensing instruments, thoroughly characterizing Europa's habitability.

PROJECT PURPOSE

Jupiter's moon Europa has the largest known ocean in the solar system, and is one of the most likely places to find current life beyond our Earth. For over 18 years NASA has developed concepts to explore Europa and determine if it is habitable based on characteristics of its vast oceans (twice the size of all of Earth's oceans combined), the ice surface – ocean interface, the chemical composition of the intriguing, irregular brown surface areas, and the current geologic activity providing energy to the system. After thorough investigation of concept options, NASA initiated the Phase A study of a multiple flyby mission that delivers the most science for the least cost and risk of all the concepts studied. The flyby concept takes advantage of solar power and requires no new technology development, despite the harsh radiation environment that the spacecraft will encounter during the flybys. The Clipper mission will explore Europa and investigate its habitability.

NASA established the Europa Clipper project in FY 2015, initiating the formulation phase, and competitively selected nine instruments for development. In FY 2016, the project formulated requirements, architecture, planetary protection requirements, risk identification and mitigation plans, cost and schedule range estimates, and payload accommodation for a mission to Europa. In FY 2017, the project entered its preliminary design phase, and in FY 2018 conducted approximately 21 independent or peer reviewed preliminary design reviews at the sub-system, system or instrument level.

Costs and schedule for the Europa Clipper mission are not baselined, as the mission is still in formulation and NASA does not commit to costs and schedules until KDP-C. The budget provides no funding for a

EUROPA CLIPPER

Formulation	Development	Operations

multi-billion-dollar mission to land on Europa that was not in the last Decadal Survey and would send another flagship mission to Europa before analysis of the Europa Clipper data is completed.

EXPLANATION OF MAJOR CHANGES IN FY 2019

The FY 2019 request enables a launch readiness date of 2025 for the Europa Clipper.

PROJECT PRELIMINARY PARAMETERS

NASA formulated the Europa Clipper mission in response to the National Research Council’s Vision and Voyages for Planetary Science in the Decade 2013-2022 (2011), which identified a strategic mission to Europa as the second highest priority for planetary science flagship missions. This mission will leverage the selected payload of nine investigations to characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of the surface-ice ocean exchange. It will also understand the habitability of Europa’s ocean through composition and chemistry of the surface and exosphere; understand the formation of surface features, including sites of recent or current activity; and identify and characterize high science interest localities. This will be the first NASA mission explicitly designed to explore an ocean world.

The Europa Clipper mission will spend four years in orbit around Jupiter, conducting its scientific observations by completing multiple close fly-bys of Europa, minimizing the spacecraft's exposure to the harsh radiation environment near Europa.

The Administration proposes to launch the Clipper on a commercial launch vehicle, which would be several hundreds of millions of dollars cheaper than an SLS flight. While the Administration recognizes the benefits of using an SLS vehicle, including a shorter cruise to Europa and a more direct trajectory (enabling a simpler thermal design), the additional costs of adding an SLS flight for the Clipper outweigh the benefits. Additionally, the Deep Space Exploration Systems program, under which SLS is managed, will be focused on supporting the Administration’s new space exploration strategy and prioritizing the return of astronauts to the surface of the Moon. Consistent with Public Law 115-31, NASA is currently maintaining the capability to launch the Clipper on an SLS rocket.

ACHIEVEMENTS IN FY 2017

The Europa Clipper mission passed its KDP-B gate review in February 2017 and is in the preliminary design and technology completion phase (Phase B).

WORK IN PROGRESS IN FY 2018

The Europa Clipper mission will continue its preliminary design and technology development efforts and complete numerous preliminary design reviews. The project will procure long lead parts in FY 2018.

EUROPA CLIPPER

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2019

After successfully completing numerous preliminary design reviews, the Europa Clipper mission will advance from Phase B (preliminary design and technology completion) to Phase C (final design and fabrication) at the beginning of FY 2019. This review will formally establish and baseline the cost and schedule commitments for this mission. Following confirmation, final designs will be determined and critically reviewed.

Budget for 2022 Launch

Per Public Law 114-113, Division B, Title III, the following table provides rough estimates for the current mission design, including launch vehicle, assuming launch in 2022. NASA does not recommend acceleration of the launch to 2022, given potential impacts to the rest of the Science portfolio. The Administration supports a balanced science program, as recommended in the Decadal Survey.

	FY18	FY19	FY20	FY21	FY22	FY 23
Europa 2022 ($M)	410.0	565.0	594.0	479.0	397.0	102.0

The profile assumes $432 million for a commercial launch vehicle, which may be reduced as commercial offerings and pricing continue to evolve. It is not possible to launch the Clipper on an SLS earlier than 2024 without disrupting current NASA human exploration plans.

ESTIMATED PROJECT SCHEDULE

The dates below are consistent with launch in 2022. As noted above, costs and schedule for the Europa Clipper mission are not baselined, as the mission is still in formulation and NASA does not commit to costs and schedules until KDP-C.

Milestone	Formulation Authorization Document	FY 2019 PB Request
Formulation Authorization	Apr 2015	April 2015
SRR	Jun 2016	Jan 2017
KDP-B	Jul 2016	Feb 2017
PDR	Mar 2019	Aug 2018
KDP-C	May 2019	Oct 2018
CDR		Nov 2020
SIR		Oct 2021
KDP-D	TBD	Dec 2021
Launch (or equivalent)	TBD	TBD

EUROPA CLIPPER

Formulation	Development	Operations

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or preliminary design review.

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
Feb 2017	3,100-4,000	LRD	Jun 2022 - Jul 2023

Project Management & Commitments

Responsibility for Europa Clipper project management resides at JPL, with program management authority assigned to MSFC.

Element	Description	Provider Details	Change from Formulation Agreement
Spacecraft		Provider: JPL Lead Center: JPL Performing Center(s): JPL, APL, GSFC, MSFC, JSC, KSC Cost Share Partner(s): N/A	
Europa UVS Instrument	Ultraviolet Spectrograph	Provider: SwRI Lead Center: JPL Performing Center(s): SwRI Cost Share Partner(s): N/A	
MASPEX	Time-of-Flight Mass Spectrometer	Provider: SwRI Lead Center: JPL Performing Center(s): SwRI Cost Share Partner(s): N/A	
Europa Imaging System (EIS)	Narrow Angle and Wide Angle cameras	Provider: APL Lead Center: JPL Performing Center(s): APL Cost Share Partner(s): N/A	

EUROPA CLIPPER

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
SUDA	Dust Analyzer; Mass Spectrometer	Provider: LASP - CU Lead Center: JPL Performing Center(s): LASP - CU Cost Share Partner(s): N/A	
E-THEMIS	Thermal Imager	Provider: ASU Lead Center: JPL Performing Center(s): ASU, BATC Cost Share Partner(s): N/A	
ICEMAG	Magnetometer	Provider: JPL Lead Center: JPL Performing Center(s): JPL, UCLA Cost Share Partner(s): N/A	
PIMS	Plasma Instrument - Faraday Cups	Provider: APL Lead Center: JPL Performing Center(s): APL Cost Share Partner(s): N/A	
MISE	Infrared Spectrometer	Provider: JPL Lead Center: JPL Performing Center(s): JPL, APL Cost Share Partner(s): N/A	
REASON	Sounding Radar	Provider: Univ. of Texas Lead Center: JPL Performing Center(s): JPL, UT, U. Iowa Cost Share Partner(s): N/A	

EUROPA CLIPPER

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
Launch Vehicle uncertainty due to congressional direction on using an SLS and Administration position on using a commercial launch vehicle	Maintaining compatibility with both EELV and SLS. Assessing information on launch vehicles in development as it becomes available. Regular meetings with SLS on performance, interfaces, and environments. If the Congress were to support the Administration’s position, NASA could move forward this year with securing a commercial launch vehicle.
Radiation Effects (including total dose, spacecraft charging, and internal electrostatic discharge)	Early parts testing for radiation tolerance and lot buys of compatible parts made available to subsystems and instruments; development of preferred parts list; early radiation modeling to optimize shielding.
Planetary Protection and Flight System Bioburden Reduction	Early and regular engagement with the Planetary Protection Officer and planning for bioburden reduction efforts and assessment.

Acquisition Strategy

The Europa Clipper spacecraft is a JPL "in-house" build with each subsystem doing its internal make/buy assessment, with competed industry contracts where appropriate. JPL has entered into a partnership with APL for this build, leveraging each other's strengths as well as those of other NASA centers. As a result, APL is responsible for propulsion module and the telecom subsystem, and GSFC will be providing the propulsion subsystem. The Europa Clipper payload comprises nine investigations, each competitively selected via a SMD AO.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Telecom and Propulsion Subsystems	APL	Laurel, MD Greenbelt, MD (GSFC)
EIS instrument	APL	Laurel, MD
PIMS instrument	APL	Laurel, MD
REASON instrument	University of Texas JPL U. of Iowa	Austin, TX Pasadena, CA Iowa City, IA
MISE instrument	JPL APL	Pasadena, CA Laurel, MD
ICEMAG instrument	JPL	Pasadena, CA

EUROPA CLIPPER

Formulation	Development	Operations

Element	Vendor	Location (of work performance)
SUDA instrument	LASP - University of Colorado	Boulder, CO
MASPEX instrument	SWRI	San Antonio, TX
UVS instrument	SWRI	San Antonio, TX
E-THEMIS instrument	ASU Ball Aerospace Raytheon Vision Systems	Tempe, AZ Boulder, CO Goleta, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Jan 2017	Europa SRR and MDR	SRB recommend project proceed into phase B	Aug. 2018
Performance	SRB	Aug 2018	PDR	TBD	Nov 2019
Performance	SRB	Nov 2019	CDR	TBD	Sep 2020
Performance	SRB	Sep 2020	SIR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
JUICE - Jupiter Icy Moons Explorer	22.9	--	**10.3**	5.1	5.3	5.1	6.0
Outer Planets Research	7.5	--	**8.5**	8.5	8.5	8.5	8.5
Cassini	54.1	--	**2.1**	0.0	0.0	0.0	0.0
Total Budget	**84.5**	**--**	**20.9**	**13.6**	**13.8**	**13.6**	**14.5**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Other Missions and Data Analysis includes the Jupiter Icy Moons Explorer (JUICE), Outer Planets Research, and the operating mission Cassini.

Mission Planning and Other Projects

JUICE-JUPITER ICY MOONS EXPLORER

NASA is collaborating with ESA on this ESA-led mission to Ganymede and the Jupiter system. The JUICE mission provides an opportunity for comparative investigation of three of the ocean worlds in the Jupiter system: Europa, Ganymede, and Callisto. Researchers believe Ganymede and Callisto possess liquid water oceans sandwiched between ice layers deep beneath their surfaces. ESA plans to launch the mission in 2022 for arrival at Jupiter in 2030. It has a tentative model payload of 11 scientific instruments. The NASA contribution consists of three separate pieces of hardware: one full instrument, Ultra Violet Spectrometer (UVS); two sensors for the Particle Environment Package suite of instruments (PEP-Hi); and the transmitter and receiver hardware for the Radar for Icy Moon Exploration (RIME) instrument.

Recent Achievements

The JUICE UVS instrument successfully held its CDR in September 2017 with the RIME and PEP-Hi CDRs scheduled for the first half of 2018.

OUTER PLANETS RESEARCH

Outer Planets Research increases the scientific return of current and past NASA outer planets missions, guides current mission operations (e.g., selecting Cassini imaging targets), and paves the way for future missions (e.g., refining landing sites on Titan, reconsidering the ice shell thickness on Europa).

OTHER MISSIONS AND DATA ANALYSIS

RECENT ACHIEVEMENTS

A new analysis showed that the magnetospheric structure at Titan's orbit is much more complex and variable on short timescales than previously thought, and this can drive significant variations in the Titan plasma interaction, which in turn affects Saturn's larger magnetosphere. Meanwhile, work continues on understanding Titan's weather. Titan has weather like Earth, though liquid methane replaces the liquid water in Earth's weather systems at the extremely cold temperatures on Titan. Cassini has observed areas with steady precipitation, though these areas are limited and cannot account for the many of the liquid-carved surface features Cassini has revealed. The influence of extreme precipitation on Titan in these areas with less regular rainfall has been demonstrated by showing that alluvial fans (liquid-generated surface features) are not found in regions of steady precipitation but rather in regions where the most extreme storms and most variable rainfall occur. Though the rains on Titan fall gently on the plains, in other areas there are occasional torrential downpours that cause flooding.

Operating Missions

CASSINI

Cassini is a flagship mission that ended its 13-year exploration of Saturn in September 2017. It vastly increased our understanding of the planet, its famous rings, magnetosphere, icy satellites, and particularly the moons Titan and Enceladus. Cassini completed its prime mission in July 2008, completed its Equinox extended mission in July 2010, and began the Solstice extended mission in October 2010. It has finished its detailed exploration of the Saturn system, including its rings and moons. A major focus was on the ocean worlds in the Saturn system, Titan (Saturn's largest moon), with its dense atmosphere, methane-based meteorology, and geologically active surface; and Enceladus, a tiny icy body with its unexpected global ocean and steady plumes ejecting water from the South Pole. The Solstice mission observed seasonal and temporal change in the Saturn system, especially at Titan, to understand underlying processes and prepare for future missions. In FY 2017, an encounter with Titan changed its orbit in such a way that, at closest approach to Saturn, it would be only about 1,800 miles above the planet's cloud tops, and below the inner edge of the D ring. This sequence of approximately 22 orbits, named the Grand Finale, provided an opportunity for an entirely different mission for the Cassini spacecraft, investigating science questions never anticipated at the time Cassini launched. The Cassini mission ended September 15, after the proximal orbits when a final encounter with Titan sent the Cassini probe into Saturn's atmosphere.

Recent Achievements

The Cassini mission completed its exploration of the Saturn system, including the sequence of orbits named the Grand Finale. The mission provided an incredibly rich dataset that will take years to analyze completely.

TECHNOLOGY

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**183.3**	**--**	**210.2**	**200.2**	**200.0**	**200.0**	**200.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

MMRTG undergoing acceptance testing at Idaho National Laboratory.

Planetary Science missions demand advances in technology to enable successful trips to distant solar system destinations, harsh environments, and missions with highly challenging trajectories and operations. To meet these needs, Planetary Science supports the development of advanced multi-mission capabilities through technology investment in key spacecraft systems, such as power, propulsion, and mission operations. The Planetary Science Technology program includes the Radioisotope Power System (RPS) Program managed by Glenn Research Center, DOE-managed Plutonium production and Production Operations infrastructure, Planetary Science Exploration Technology and Advanced Multi-Mission Operations System (AMMOS) projects.

EXPLANATION OF MAJOR CHANGES IN FY 2019

With Pu 238 production going operational in FY 2019, the Plutonium and the DOE Radioisotope Power System Infrastructure projects have been integrated to manage the supply chain for production of new Pu 238, full clad assemblies, infrastructure, and RPS proficiencies as efficiently as possible.

ACHIEVEMENTS IN FY 2017

The RPS Program awarded four contracts to assess the state of Stirling technologies across industry and define goals and requirements for future Stirling development projects. RPS will continue to advance towards a gate review of the Skutterudite thermoelectric technology transfer effort and develop the plan for the next phase. Additionally, the RPS Program supported the New Frontiers AO, allowing for a potential mission requirement for MMRTGs or Radioisotope Heater Units. As part of preparing to support future flight missions that require nuclear power, such as New Frontiers, NASA worked with

TECHNOLOGY

DOE to develop a constant fuel clad production process, which will reduce schedule risk and mission support cost.

NASA's Advanced Technology project competitively selected mission concept studies, under the Small Innovative Missions for Planetary Exploration call, to identify high-priority planetary science objectives that CubeSats and SmallSats can address, and to guide NASA’s development of small spacecraft technologies relevant to deep space science investigations. These selections span a broad range of science objectives and spacecraft configurations, and will inform the design of future planetary smallsat missions. This activity is the Planetary Science component of the broader SmallSat/CubeSat initiative discussed in the Science overview section of this document.

NASA's Advanced Technology project competitively awarded research grants for development of high temperature (greater than 500 degrees Celsius) electronic components to survive on the surface of Venus, the hottest planetary destination in the solar system. This research will enable the future development of long-lived landers for Venus.

NASA's Icy Satellites Technology project competitively awarded research grants for development of technology required to land explore, and investigate the icy moons of Jupiter or Saturn. These awards included concepts specific to life detection technology, helping to develop the technology for future landed missions to the icy satellites.

WORK IN PROGRESS IN FY 2018

The RPS Program supports Mars 2020 by providing an MMRTG flight unit in FY 2018 for preparation for fueling, assembly, test, and launch operations. DOE will be performing its second plutonium production demonstration as part of its efforts to restart plutonium production. LANL will be installing the new plutonium hot press that will reduce the schedule risk for producing plutonium fuel clad assemblies to future NASA missions.

Planetary Science proposed a new solar system robotic exploration technology initiative in 2018. The new Planetary Exploration Science Technology Office will lead this effort. This initiative will accelerate technological innovations that will change the paradigm for robotic solar system exploration, such as small satellite technologies to enable solar system exploration using small satellites and/or cubesats; life-detection instruments; and/or commercial partnerships to support future robotic solar system exploration.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

This project will develop new technology based upon advanced technology work begun in 2017 in high temperature electronics, and icy satellite technologies.

TECHNOLOGY

Program Elements

DOE OPERATIONS AND ANALYSIS

NASA funds the DoE personnel and infrastructure required to maintain the capability to develop and fuel radioisotope power systems for deep space spacecraft missions. DoE performs the work required for NASA. NASA and DoE are restarting domestic production of Plutonium-238 for the first time since the 1980's. NASA funds the effort and the DOE Oak Ridge National Laboratory leads the effort, and irradiates targets at their High Flux Isotope Reactor. The DOE Idaho National Lab participates in the development of targets for future irradiation at the Advanced Test reactor, which will be required to support target production rates. An initial production of 100 grams was achieved in FY 2016, and as the process is refined and automated over the next several years, it is expected to ramp up to a full operational capability of 1.5 kilograms per year. In FY2019, the NASA incorporated the Plutonium project into the DOE Operations and Analysis budget as part of the DOE Constant Rate Production plan to better support NASA missions by producing plutonium heat sources at a constant rate, as opposed to periodic mission focused campaigns.

ADVANCED TECHNOLOGY

NASA continues to study emerging planetary mission requirements to identify needs for new technology investment. NASA also engages with stakeholders to ensure the relevance and priorities for existing investments, consistent with the NASA Strategic Space Technology Investment Plan. NASA will continue investments in advanced energy production and conversion technologies and spacecraft technologies that can uniquely enable future planetary missions, including partnerships with STMD. Starting in FY 2018, NASA will focus this work on developing new approaches to planetary exploration, to reduce costs and enhance opportunities for scientific investigation through smallsat technologies and commercial partnership opportunities.

RADIOISOTOPE POWER SYSTEM

The radioisotope power system (RPS) Program is continuing technology development and certification of advanced power conversion in preparation for the development of future RPS systems, and is supporting production and certification of the MMRTG for Mars 2020.

Operating Missions

ADVANCED MULTI-MISSION OPERATION SYSTEM (AMMOS)

AMMOS provides multi-mission operations, navigation, design, and training tools and services for Planetary Science flight missions, as well as other Science Mission Directorate missions, and invests in improved communications and navigation technologies. The AMMOS project will continue to provide and develop multi-mission software tools for spacecraft navigation, command, control, assessment, and mission planning. In addition, AMMOS will pursue complementary collaborations with the Agency's crosscutting Space Technology program. Utilizing the AMMOS common tools and services lowers individual mission cost and risk by providing a mature base for mission operations systems at significantly reduced development time.

AMMOS also provides support to our international space agency partners, on an as-needed basis. This support typically pertains to navigation assistance and scheduling of NASA's Deep Space Network (DSN) assets.

Program Management & Commitments

Program Element	Provider
RPS Program	Provider: GRC Lead Center: GRC Performing Center(s): GRC, JPL, GSFC, KSC, DOE Cost Share Partner(s): N/A
Plutonium	Provider: DOE Lead Center: GRC Performing Center(s): GRC, DOE Cost Share Partner(s): N/A
DoE Operations and Analysis	Provider: DOE Lead Center: GRC Performing Center(s): GRC, DOE Cost Share Partner(s): N/A
Planetary Science Exploration Technology	Provider: N/A Lead Center: Headquarters Performing Center(s): ARC, GRC, GSFC, LaRC, JPL, JSC, MSFC Cost Share Partner(s): N/A
AMMOS	Provider: JPL Lead Center: JPL Performing Center(s): JPL, GSFC, JSC, ARC, MSFC, APL Cost Share Partner(s): N/A

Acquisition Strategy

DOE provides radioisotope power systems, production operations, and the Plutonium production projects on a reimbursable basis. The Planetary Science Exploration Technology project will fund competitively selected activities from the ROSES omnibus research announcement.

ASTROPHYSICS

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	FY 2020	Notional FY 2021	FY 2022	FY 2023
Astrophysics Research	190.1	--	**259.2**	280.8	321.5	318.4	310.0
Cosmic Origins	779.4	--	**491.4**	354.5	311.9	312.7	312.7
Physics of the Cosmos	106.2	--	**136.8**	139.1	113.3	108.3	105.0
Exoplanet Exploration	152.6	--	**52.4**	44.5	44.6	44.4	44.9
Astrophysics Explorer	124.1	--	**245.6**	366.5	394.0	401.6	412.8
Total Budget	**1352.3**	--	**1185.4**	**1185.4**	**1185.4**	**1185.4**	**1185.4**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Astrophysics

ASTROPHYSICS RESEARCH

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Astrophysics Research and Analysis	73.5	--	**83.4**	86.6	90.2	92.2	94.2
Balloon Project	34.0	--	**39.2**	41.7	40.4	40.5	40.6
Science Activation	37.0	--	**44.6**	44.6	44.6	44.6	44.6
Other Missions and Data Analysis	45.6	--	**92.0**	108.0	146.4	141.1	130.7
Total Budget	**190.1**	**--**	**259.2**	**280.8**	**321.5**	**318.4**	**310.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

The Primordial Inflation Polarization Explorer (PIPER) balloon-borne experiment searches for the signature of primordial gravity waves excited by an inflationary epoch in the early universe by studying the cosmic microwave background. The picture above shows the payload on the launch vehicle in Ft Sumner, NM shortly before its successful launch on October 13, 2017.

The Astrophysics Research program develops innovative technologies for future missions to explore and understand the cosmos, from the nature of planets circling other stars to the birth of distant galaxies and the earliest cosmic history. High-altitude balloon and sounding rocket flights test new types of instruments. These flights also allow a quick response to unexpected events, such as the appearance of a new supernova.

The program provides basic research awards for scientists to test their theories and to understand how they can best use data from NASA missions to gain new knowledge from the cosmos. Awardees analyze the data from Astrophysics missions to understand astronomical events, such as the explosion of a star or the fingerprints of early cosmic history in the microwave background.

EXPLANATION OF MAJOR CHANGES IN FY 2019

The Research and Analysis budget includes a significant increase in FY 2019, enabled by redirecting funds made available due to the proposed termination of WFIRST. Funding for the civil servants previously planned within WFIRST is carried within Other Missions and Data Analysis.

ASTROPHYSICS RESEARCH

ACHIEVEMENTS IN FY 2017

The Colorado High-resolution Echelle Stellar Spectrograph (CHESS) launched on a sounding rocket in FY 2017. CHESS tested new high collecting-area, high-resolution ultraviolet dispersion gratings. It observed some of the brightest stars in the constellation Scorpio, surrounded by translucent clouds that will eventually merge to form new stars and planets. These observations will give an accurate inventory of both the hydrogen and the carbon in the clouds, providing clues to the types of planets that may form.

The Balloon project supported the annual Antarctic long-duration balloon flights, a super-pressure balloon campaign to New Zealand, and two conventional balloon campaigns from Palestine, TX and Fort Sumner, NM.

In FY 2017, three long-duration balloons launched from McMurdo Station, Antarctica. The first payload, named BACCUS (Boron and Carbon Cosmic rays in the Upper Stratosphere), is designed to measure the elemental spectra of cosmic rays to very high energies. BACCUS advanced our understanding of the acceleration mechanisms that drive cosmic rays to their extreme energies. This payload flew for 30 days. The second balloon instrument, the Antarctic Impulsive Transient Antenna (ANITA), can detect neutrinos by their distinct radio impulse. ANITA produced interactions in the ice sheet below. The experiment aims to identify and characterize the highest energy astrophysical accelerators in the universe. It flew for 27 days. The third payload, the Stratospheric Terahertz Observatory (STO2), used far-infrared light to trace molecules. STO2 used interstellar gas through the life cycle from molecular clouds to star formation. It flew for 22 days.

NASA completed the reconfiguration of the successful balloon-borne Cosmic Ray Energetics and Mass (CREAM) payload to fly on the International Space Station (ISS). On August 14, 2017, ISS-CREAM launched on a SpaceX rocket and is now operating on the ISS. The science team is working on on-orbit calibration before transitioning to the science mode.

Research on exoplanets confirmed the nature of exoplanet candidates and explored the nature of planets circling other stars. In addition, theoretical and computational efforts advanced our understanding of how black holes merging release gravitational waves.

WORK IN PROGRESS IN FY 2018

NASA has scheduled seven Astrophysics sounding rockets for launch in FY 2018. Two of these will fly from the Kwajalein atoll performing high-resolution spectroscopy in the x-ray and ultraviolet parts of the spectrum. Both flights will test out new water recovery systems. Four sounding rockets will fly from the White Sands Missile Range. The first sounding rocket experiment will study the impact of star formation on stellar environments; the second will use an advanced micro calorimeter detector to obtain high-resolution spectral data from the Puppis A supernova remnant; the third will study the diffuse infrared background; and the fourth will measure the absolute calibration of stars from infrared to ultraviolet wavelengths. A single sounding rocket experiment will launch from Poker Flats to study the diffuse x-ray background.

NASA is planning four science payloads for the FY 2018 Palestine, TX campaign. The fall 2018 Fort Sumner, NM campaign will involve four science launches, two student-led launches, and two technology test launches.

ASTROPHYSICS RESEARCH

KEY ACHIEVEMENTS PLANNED FOR FY 2019

NASA will continue a competed Astrophysics Research program with emphasis on suborbital payloads and on development of key technologies for use in future missions. Theoretical work will provide the foundation to develop science requirements for new missions. Data analysis will multiply the science yield from NASA's astrophysics missions.

The Sounding Rocket program is planning a campaign in Australia in 2019. This will allow flights to observe celestial targets in the Southern Hemisphere. At least two research groups plan to launch Astrophysics experiments on sounding rockets in FY 2019 from the Northern Hemisphere. One investigation will test out new, high resolution x-ray gratings for spectroscopy. The other will measure the absolute flux of nearby UV-bright stars in the extreme UV, a region in which the existing data is poorly calibrated.

The Balloon project plans to support two campaigns outside the continental U.S., including the annual Antarctic long-duration balloon flights and a super-pressure balloon launch from New Zealand, plus two domestic campaigns with conventional balloon flights from Palestine, TX, and Fort Sumner, NM.

The Antarctic campaign plans to launch three payloads for science investigations. The first payload will study the polarization of x-ray sources; the second payload will employ a submillimeter telescope to study the effects of magnetic fields on star formation; and the third payload will search for signature of inflation in the cosmic microwave background using transition edge sensors.

The Palestine, TX campaign plans to launch at least four payloads for science investigations. The first balloon payload will map the cosmic microwave background (PIPER); the second payload will study weak lensing of galaxy clusters and cosmic shear (SuperBIT); the third payload is a medium-energy gamma-ray instrument with greater capability than the Comptel instrument (ASCOT); and the fourth payload will study the cosmic microwave background (BOBCAT).

The Fort Sumner, NM campaign in the fall of 2018 plans to launch four science investigations in addition to student and technology demonstration launches. The first payload will map the cosmic microwave background (PIPER), the second payload will test a new technology for direct imaging of exoplanets (PICTURE-C), the third payload will provide in-situ measurements needed to cross-calibrate space missions (REMOTE), and the fourth payload will study weak lensing of galaxy clusters and cosmic shear (SuperBIT).

ISS-CREAM science operations will continue in FY 2019.

During FY 2019, NASA will enhance its investment in CubeSats/SmallSats that can achieve specific Astrophysics objectives at low cost.

Program Elements

RESEARCH AND ANALYSIS

This project supports basic research, solicited through NASA's annual Research Opportunities in Space and Earth Sciences (ROSES) announcements. NASA solicits investigations relevant to Astrophysics over

ASTROPHYSICS RESEARCH

the entire range of photon energies, gravitational waves, and particles of cosmic origin. Scientists and technologists from a mix of disciplines review proposals and provide findings that underlie NASA's merit-based selections. To better support strategic research investment for the community, this budget supports a rebalance of fellowship awards and research grants.

Astrophysics Research and Analysis solicits technology development for detectors and instruments for potential use on future space flight missions and science and technology investigations using sounding rockets, high-altitude balloons, and similar platforms. A new type of scientific instrument often flies first on a stratospheric balloon mission or on a sounding rocket flight, which takes it briefly outside Earth's atmosphere. Instruments for balloons and sounding rockets are less expensive than orbital missions, and experimenters can build them quickly to respond to unexpected opportunities, such as a newly discovered supernova. The experimenter usually retrieves the equipment after the flight so that new instruments can be tested, improved, and flown again. Suborbital flights are important for training the next generation of scientists and engineers to maintain U.S. leadership in STEM. The project also supports small experiments to be flown on the ISS, laboratory astrophysics, and limited ground-based observations.

The Astrophysics Theory program element solicits basic theory investigations needed to interpret data from NASA's space astrophysics missions and to develop the scientific basis for future missions. Astrophysics Theory topics include the formation of stars and planets, supernova explosions and gamma-ray bursts, the birth of galaxies, dark matter, dark energy, and the cosmic microwave background.

The Exoplanet Research program element solicits observations to detect and characterize planets around other stars and to understand their origins.

The Nancy Grace Roman Technology Fellowship develops early career researchers, who could lead future flight instruments and missions. Initially, NASA identifies promising early career researchers and supports their investigations. NASA then selects a subset of fellows for additional funding to start a laboratory or develop a research group at the Fellow's institution.

The NASA ISS-CREAM experiment is a former balloon payload, which is now operating on the ISS. The science goal is to extend the reach of direct measurements of cosmic rays to the highest energy possible, to probe their origin, acceleration, and propagation. The long exposure provided by the ISS above the atmosphere offers more than an order of magnitude improvement in data, yielding much greater statistical accuracy and lower background noise. The University of Maryland in College Park leads the ISS-CREAM mission, with collaboration teams from the United States, South Korea, Mexico, and France.

SCIENCE ACTIVATION

he FY 2019 Budget continues support for multi-year Science Activation awards made in 2016. The peer-evaluated competition produced 27 awards that deliver SMD's unique content and expertise more efficiently and effectively into the learning environment for learners of all ages. Based on recommendations from the National Academies and other stakeholders, the awardees of these cooperative agreements work collaboratively with each other. They also work with local and national partners to achieve a multiplier effect utilizing NASA and SMD investments. The number of awardees in 2019 is reduced to 24 due to the phasedown of awardees that supported the successful 2017 total solar eclipse. A recent University of Michigan survey found that 88 percent of U.S. adults (an estimated 215 million) saw the eclipse in person, on television, or online.

ASTROPHYSICS RESEARCH

By 2020, the program aims to enable learners in all 50 states; improve U.S. scientific literacy; support Federal STEM Education Five-Year Strategic Plan goals; and increase the number of strategic partners, as appropriate, to enhance the overall effort.

The budget supports all planned activities within SMD's Science Activation program. All awards include independent evaluation to assess the merits of the program.

BALLOON PROJECT

The Balloon project offers inexpensive, high-altitude flight opportunities for scientists to conduct research and test new technologies before space flight application. Balloon experiments cover a wide range of disciplines in astrophysics, solar physics, heliospheric physics, and Earth upper-atmosphere chemistry as well as selected planetary science, such as comet observations. Observations from balloons have even detected echoes of the Big Bang and probed the earliest galaxies. The Balloon project continues to increase balloon size and enhance capabilities, including an accurate pointing system to allow high-quality astronomical imaging and a super-pressure balloon that maintains the balloon's integrity at a high altitude to allow much longer flights at mid-latitudes that include nighttime viewing of astronomical objects.

Program Schedule

The program issues solicitations every year. A Senior Review process assesses all missions in the extended operations phase every three years and all data archives every three or four years.

Date	Significant Event
Mar 2016	Senior Review Operating Missions
Feb 2017	NASA Research Announcement (NRA) Solicitation
Feb 2018	NRA Solicitation
Mar 2019	Senior Review Operating Missions
Feb 2019	NRA Solicitation
Apr 2020	Senior Review Data Archives
Feb 2020	NRA Solicitation
Feb 2021	NRA Solicitation
Mar 2022	Senior Review Operating Missions

ASTROPHYSICS RESEARCH

Program Management & Commitments

Program Element	Provider
Research and Analysis Project	Provider: All NASA Centers Lead Center: Headquarters (HQ) Performing Center(s): All Cost Share Partner(s): N/A
Balloon Project	Provider: Wallops Flight Facility (WFF) Lead Center: WFF Performing Center(s): WFF Cost Share Partner(s): N/A

Acquisition Strategy

NASA issues solicitations for competed research awards each February through ROSES. Panels of scientists conduct peer reviews on all proposals. A Senior Review process reviews all missions in extended operations phase every three years, and all data archives every three or four years.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Balloon Management	Operation of the Columbia Scientific Balloon Facility in Palestine, TX Orbital-ATK	Palestine, TX and other balloon launch sites

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Archives Senior Review Panel	2015	A comparative evaluation of Astrophysics data archives	Recommended improvements in archives	2019
Quality	Astrophysics Research Program Review Panel	2011	Review of competed research projects	Panel praised scope and impact of programs	TBD
Quality	Mission Senior Review Panel	2019	A comparative evaluation of Astrophysics operating missions	Ranking of missions, citing strengths and weaknesses	2019, 2022, 2025

ASTROPHYSICS RESEARCH

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Independent Evaluation of STEM Science Activation	2017	Validation of approach and Logic Model	Baseline towards meeting overall Desired Outcome by 2020	Annual

OTHER MISSIONS AND DATA ANALYSIS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Astrophysics Directed R&T	0.0	--	**39.0**	54.4	59.1	51.3	39.9
Contract Administration, Audit & QA Svcs	12.6	--	**12.7**	12.7	12.7	12.7	12.7
Astrophysics Senior Review	0.0	--	**0.0**	0.0	31.5	33.0	33.0
Astrophysics Data Program	17.6	--	**19.1**	20.4	21.6	22.6	23.6
Astrophysics Data Curation and Archival	15.4	--	**21.2**	20.5	21.5	21.5	21.5
Total Budget	**45.6**	**--**	**92.0**	**108.0**	**146.4**	**141.1**	**130.7**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Floating clouds of the interstellar medium are the focus of the NASA-funded CHESS sounding rocket mission, which investigates the earliest stages of star formation. Here, the CHESS payload joins with the sounding rocket before launch. CHESS launched on June 27, 2017, at 1:10 a.m. EDT from the White Sands Missile Range in New Mexico.

The Astrophysics Research program prepares for the next generation of missions through both theoretical research and applied technology investigations. This program uses data from current missions and suborbital science investigations to advance NASA’s science goals. One of these goals is to create new knowledge as explorers of the universe, and to use that knowledge for the benefit of all humankind.

Mission Planning and Other Projects

DIRECTED RESEARCH AND TECHNOLOGY

This project funds the civil service staff that will work on emerging Astrophysics projects, instruments, and research. FY 2019 funding for the civil servants previously planned for WFIRST is shown within Astrophysics Directed R&T. NASA will identify work for those employees and propose funding transfers to other Projects in an FY 2019 Operating Plan.

CONTRACT ADMINISTRATION, AUDIT, AND QUALITY ASSURANCE SERVICES

This project provides critical safety and mission product inspections and contract audit services from the Defense Contract Management Agency and Defense Contract Audit Agency, respectively. It also provides for contract assurance audits, assessments, and surveillance by the NASA Contract Assurance Services Program.

ASTROPHYSICS SENIOR REVIEW

The Astrophysics Senior Review project enables extension of the life of current operating missions. Every three years, the Astrophysics division conducts a senior review to do comparative evaluations of all operating missions that have successfully completed or are about to complete their prime mission operation phase. The senior review findings help NASA prioritize which missions will receive funding for extended operations. The next Senior Review will take place in spring 2019.

ASTROPHYSICS DATA ANALYSIS PROGRAM (ADAP)

ADAP solicits research that emphasizes the analysis of NASA space astrophysics data archived in the public domain at one of NASA's Astrophysics Data Centers. With the ongoing successful operation of a portfolio of missions, ranging from modest Explorer-class missions like Swift and the Nuclear Spectroscopic Telescope Array (NuSTAR) to the great observatories Hubble and Chandra, the size and scope of NASA's archival astronomical data holdings continue to grow. Investigations funded under the ADAP ensure that NASA's astrophysics data holdings continue to be the subject of vigorous scientific analysis, thereby maximizing the scientific return on NASA mission investments.

Recent Achievements

The scope of the investigations conducted under the ADAP include focused investigations involving novel analyses of archival data from a single mission, as well as broad investigations that combine data from multiple missions to span a wide range of the electromagnetic spectrum. Such multi-mission, multi-wavelength studies are almost exclusively the province of the ADAP and are a particularly exciting aspect of the program, especially since combinations of data collected by different missions operating in different regions of the spectrum often yield new scientific insight beyond that derived from the original observations individually.

During FY 2017, the ADAP supported more than 160 science investigators at institutions across the United States. The investigations span the range from searching for potentially habitable planets in the solar neighborhood to exploring the emergence and evolution of the first galaxies in the early universe. In addition, the program supports two citizen science programs – planethunters.org and diskdetective.org – that together are engaging thousands of people in the search for planets, and planetary systems using archival data from a variety of NASA missions.

ASTROPHYSICS DATA CURATION AND ARCHIVAL RESEARCH (ADCAR)

The Astrophysics Data Centers constitute an ensemble of archives that receives processed data from individual missions and makes them accessible to the scientific community. After the completion of a mission, the relevant, active, multi-mission archive takes over all data archiving activities. ADCAR covers the activities of the Astrophysics Data Centers and the NASA Astronomical Virtual Observatories (NAVO).

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

The Astrophysics Data Centers tackled challenges and opportunities presented by a tremendous growth of content, and collaborated effectively on integrated infrastructure in support of the NAVO. In FY 2017, the Astrophysics Data System added over 1 million records and 10 million citations to its bibliographic databases, bringing the total number of publications to 12.6 million and citations to 100 million. Additional workflows and services are now available under its new, cloud-based Application Programming Interface. The Mikulski Archive for Space Telescopes (MAST) handled 35 million database searches and delivered over 422 terabytes of data to users; more than 1,300 scientific publications referenced use of the data. The data holdings of MAST were more than doubled, and programmatic user queries to their catalog holdings and observation holdings both increased by more than a factor of 50.

The High Energy Astrophysics Science Archive Center (HEASARC) continued to support active NASA missions Chandra, Fermi, NuSTAR, and Swift, NASA's international collaboration with ESA's XMM-Newton observatory, and the legacy archive for 40+ past high-energy astrophysics missions. HEASARC staff participated in all dataflow and mission readiness tests for the U.S. NICER mission, and NICER data began to flow into the HEASARC in September. HEASARC completed the reprocessing of the entire Suzaku and Hitomi archives, and made the data made publicly available. The archive total volume exceeded 100 terabytes for the first time, and the HEASARC responded to over 20 million user queries.

The Infrared Science Archive (IRSA) responded to over 30 million queries. All major IRSA data sets (images, catalogs, and spectra) are now available through Virtual Observatory (VO) protocols. IRSA released approximately 20 new datasets, including the 2017 NEOWISE Data Release, the Herschel SPIRE Point Source Catalog, and an updated Planck Public Release 2. IRSA released a Time Series Tool that allows users to visualize light curves from WISE/NEOWISE, and designed an archive user interface for the NASA Infrared Telescope Facility (IRTF) for data available through IRSA this coming year. The NASA Extragalactic Database (NED) fielded 80 million database queries and added over 83 million new objects and cross-ids from the literature and from catalogs such as the Sloan Digital Sky Survey and the Spitzer Enhanced Imaging Products Source List. In FY 2017, approximately 675 refereed journal articles acknowledged using NED.

NAVO completed their deployment of the initial version of the NASA Virtual Observatory archive standard machine interface. For the broad range of NASA astronomy missions – in all wavelength regimes – VO-enabled tools can make positional and data base queries and download images or spectra using common protocols. During this period, the NAVO archives supported over 30 million requests for data using VO protocols. NAVO continued to lead NASA's Virtual Observatory efforts within the U.S. and world communities and completed a detailed study of the efficacy of methods for indexing very large databases.

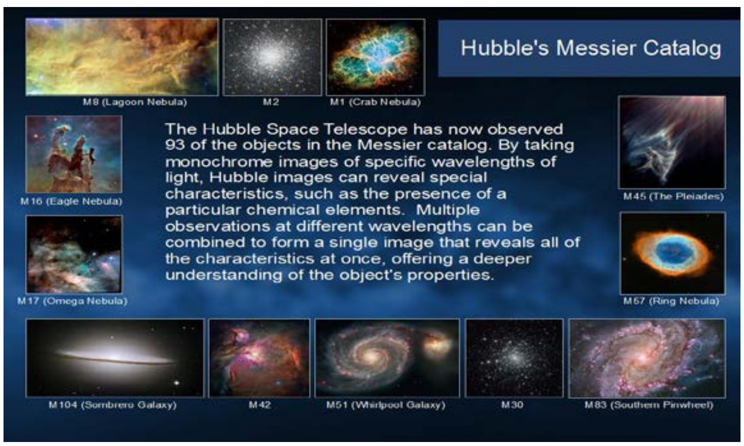
COSMIC ORIGINS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	FY 2020	Notional FY 2021	FY 2022	FY 2023
James Webb Space Telescope	569.4	533.7	**304.6**	197.2	149.8	150.0	150.0
Hubble Space Telescope Operations	97.3	--	**78.3**	88.3	93.3	98.3	98.3
Stratospheric Observatory for Infrared Astronomy (SOFIA)	85.2	--	**74.6**	39.8	16.6	0.0	0.0
Other Missions and Data Analysis	27.5	--	**33.9**	29.1	52.2	64.4	64.4
Total Budget	**779.4**	--	**491.4**	**354.5**	**311.9**	**312.7**	**312.7**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



By his death in 1817, Charles Messier had compiled a group of 103 objects known as Messier's Catalog of Nebulae and Star Clusters. The catalog includes some of the most fascinating astronomical objects that can be observed from Earth's Northern Hemisphere.

"How did we get here?" This simple but fundamental question drives the broad science objectives of NASA's Cosmic Origins program. Our search for answers raise underlying questions and topic areas, such as, how and when did the first stars and galaxies form? When did the universe first create the elements critical for life? How did galaxies evolve from the very first systems to the types we observe "in the here and now," such as the Milky Way in which we live? How do stars and planetary systems form and change over time?

No individual space observatory or airborne observatory can completely address all of these questions, but in partnership, they can begin to unravel the answers. Currently operating facilities in the Cosmic Origins program are the Hubble Space Telescope, Spitzer Space Telescope, and Stratospheric Observatory for Infrared Astronomy (SOFIA). Under development is the James Webb Space Telescope, a large, next generation, cryogenic infrared observatory to launch in 2019. Working collectively across a wide swath of wavelengths, from the far-ultraviolet through the far-infrared and sub-millimeter, these observatories create a comprehensive web of information and data that spans both the electromagnetic spectrum and time itself.

For more information, see: http://cor.gsfc.nasa.gov/.

COSMIC ORIGINS

EXPLANATION OF MAJOR CHANGES IN FY 2019

The budget reflects moving the James Webb Space Telescope into the Cosmic Origins Program of the Astrophysics Theme, where it will be managed following launch and commissioning in 2019. Due to program efficiencies and appropriation of funds above the request for the past few years, both the Hubble and SOFIA missions are carrying excess funding. This budget reflects use of excess funds from prior years, resulting in less resources requested in FY 2019. These adjustments are not expected to impact the workforce or science generated from these missions.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023	BTC	Total
Formulation	1800.1	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	1800.1
Development/Implementation	4810.6	569.4	533.7	**227.6**	47.5	0.0	0.0	0.0	0.0	6188.8
Operations/Close-out	0.0	0.0	0.0	**77.0**	149.8	149.8	150.0	150.0	160.0	836.6
2018 MPAR LCC Estimate	**6610.7**	**569.4**	**533.7**	**304.6**	**197.2**	**149.8**	**150.0**	**150.0**	**160.0**	**8825.4**
Total Budget	**6538.6**	**569.4**	**533.7**	**304.6**	**197.2**	**149.8**	**150.0**	**150.0**	**160.0**	**8753.3**
Change from FY 2018				**-229.1**						
Percentage change from FY 2018				**-42.9%**						

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Completion of Webb telescope center-of-curvature test.

PROJECT PURPOSE

The James Webb Space Telescope (Webb) is a large, space-based astronomical observatory. The mission is in many ways a successor to the Hubble Space Telescope, extending Hubble's discoveries by looking into the infrared spectrum. Webb will observe the highly red-shifted early universe and study relatively cool objects like protostars and protoplanetary disks, which emit infrared light strongly where dust obscures shorter wavelengths. With more light-collecting area than Hubble and with near- to mid-infrared-optimized instruments, Webb will observe objects farther away and further back in time.

The four main science goals are:

- Search for the first galaxies or luminous objects formed after the Big Bang;
- Determine how galaxies evolved from their formation until now;
- Observe the formation of stars from the first stages to the formation of planetary systems; and
- Measure the physical and chemical properties of planetary systems and investigate the potential for life in those systems.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

While Hubble greatly improved knowledge about distant objects, its infrared coverage is limited. Light from distant galaxies is red-shifted out of the visible part of the spectrum into the infrared by the expansion of the universe. Webb will explore the poorly understood epoch when the first luminous objects in the universe came into being after the Big Bang.

EXPLANATION OF MAJOR CHANGES IN FY 2018

NASA moved the mission launch date roughly six months later (Mar-Jun 2019) due to delays associated with the spacecraft and sunshield schedules. Two propulsion problems required additional schedule to resolve and sunshield integration took longer than planned.

PROJECT PARAMETERS

Webb is an infrared-optimized observatory that will conduct imaging and spectrographic observations in the 0.6- to 28-micrometer wavelength range. Webb will be roughly 100 times more capable than Hubble because its mirror is seven times larger. It will spend about twice as much time observing targets since the Earth will not be in the way. Its detectors cover larger regions of the sky and are always on (i.e., can always be running in parallel), and its multi-object spectroscopic capabilities greatly expands the number of spectra per field.

The 6.5-meter primary mirror consists of 18 actively controlled segments. A multilayer sunshield the size of a tennis court passively cools the mirror, telescope optics, and instruments to about 40 Kelvin. Webb will launch in 2019 from Kourou, French Guiana on an Ariane 5 rocket, contributed by the European Space Agency (ESA). Webb will operate in deep space about one million miles from Earth.

Webb’s instruments include the Near Infrared Camera, Near Infrared Spectrograph, Mid-Infrared Instrument, and the Fine Guidance Sensor / Near Infrared Imager and Slitless Spectrograph.

The Near Infrared Camera takes images with a large field of view and high resolution, over the wavelength range of 0.6 to 5 micrometers. The Near Infrared Camera also aligns and focuses the optical telescope. The Near Infrared Camera detects light from the earliest stars and galaxies in the process of formation, stars in nearby galaxies, young stars in the Milky Way, and solar system Kuiper Belt objects. The Near Infrared Camera is equipped with coronagraphs, which allow astronomers to view dimmer objects near stars. With the coronagraphs, astronomers hope to determine the characteristics of planets orbiting nearby stars.

A spectrograph disperses light from an object into a spectrum. The atoms and molecules in the object imprint lines on its spectrum that uniquely fingerprint each chemical element present. Analyzing the spectrum of an object provides information on its physical properties, including temperature, mass, chemical composition, and motion.

The Near Infrared Spectrograph can obtain simultaneous spectra of more than 100 objects in a single exposure, over the wavelength range of 0.6 to 5 micrometers.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

The Mid-Infrared Instrument takes wide-field images and narrow-field spectra, over the wavelength range of 5 to 28 micrometers. The Mid-Infrared Instrument operates at about seven degrees Kelvin, which an onboard cooling system makes possible.

The Fine Guidance Sensor is a camera that provides fine pointing control and locks the telescope onto its target. The sensor operates over a wavelength range of 1 to 5 micrometers. The Near Infrared Imager and Slitless Spectrograph instrument provides unique imaging and spectroscopic modes to investigate the distant universe, as well as exoplanets.

For more information, go to http://www.jwst.nasa.gov.

ACHIEVEMENTS IN FY 2017

NASA made significant progress in the development, fabrication, and testing of many components of the Webb system. The project also completed the following significant and technically challenging developments and tests successfully:

- Completed the environmental testing of the integrated science instruments and telescope;
- Delivered the first release of the integrated software system for Webb operations at the Space Telescope Science Institute;
- Integrated the MIRI cryocooler into the spacecraft bus;
- Completed electrical testing of the spacecraft bus;
- Completed end-to-end testing of the ground system;
- Completed the integration of the sunshield onto the spacecraft bus; and
- Completed the Missions Operations Review.

WORK IN PROGRESS IN FY 2018

In FY 2018, the project plans to complete:

- Complete cryogenic testing and test analyses of the Optical Telescope/Integrated Science module (OTIS);
- Deliver OTIS to Northrop-Grumman, Space Park for integration with the spacecraft element;
- Conduct spacecraft element environmental testing;
- Select the Early Release Science programs;
- Integrate OTIS to the spacecraft element; and
- Issue General Observers Call for Proposals for the first year of Webb observing time.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2019

The President's FY 2019 Budget request provides the full level of funding required to keep Webb on schedule for a 2019 launch. In FY 2019, the project plans to:

- Complete testing of Webb;
- Conduct testing of the Webb flight operations system and science processing system;
- Install ground support equipment at the launch site in Kourou, French Guiana;
- Transport Webb to the launch site in Kourou, French Guiana; and
- Launch Webb and start the commissioning phase of the mission.

SCHEDULE COMMITMENTS/KEY MILESTONES

NASA plans to launch Webb between March and June of 2019 to begin a five-year prime mission. The following timeline shows the development agreement schedule per the rebaseline plan from September 2011.

Milestone	Confirmation Baseline Date	FY 2019 PB Request
Key Decision Point (KDP)-C	Jul 2008	Jul 2008
Mission Critical Design Review (CDR)	Mar 2010	Apr 2010
Rebaseline/KDP-C Amendment	Sep 2011	Sep 2011
System Integration Review (SIR)	Jul 2017	Jul 2018
Launch	Oct 2018	Mar-Jun 2019
Begin Phase E	Apr 2019	Dec 2019
End of Prime Mission	Apr 2024	Dec 2024

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2012	6,197.9	66	2017	6,188.8	-0.2	LRD	Oct 2018	Mar -Jun 2019	TBD

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost. NASA originally baselined Webb in 2009, it was re-baselined in 2012. The original baseline is provided in the Supporting Data section.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**6,197.9**	**6,188.8**	**-9.1**
Aircraft/Spacecraft	2,955.0	3,482.2	527.2
Payloads	695.1	804.8	109.7
Systems Integration & Test (I&T)	288.4	448.6	160.2
Launch Vehicle	0.9	0.6	-0.3
Ground Systems	652.3	599.8	-52.5
Science/Technology	42.7	40.5	-2.2
Other Direct Project Costs	1,563.5	812.3	-751.2

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

Project Management & Commitments

NASA Headquarters is responsible for Webb program management. GSFC is responsible for Webb project management.

Element	Description	Provider Details	Change from Baseline
Observatory	Includes Optical Telescope Element (OTE), spacecraft, sunshield, observatory assembly integration and testing, and commissioning. Designed for at least a five-year lifetime. Northrop Grumman Aerospace Systems (NGAS) has the lead for the OTE, sunshield, spacecraft bus, and selected assembly, integration, and testing activities.	Provider: NGAS and GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Mission management and system engineering	Includes management of all technical aspects of mission development, and system engineering of all components.	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
ISIM	Contains the science instruments and Fine Guidance Sensor. Provides structural, thermal, power, command and data handling resources to the science instruments and Fine Guidance Sensor.	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
NIRCam	Operates over the wavelength range of 0.6 to 5 micrometers, and optimized for finding first light sources.	Provider: University of Arizona, Lockheed Martin Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
NIRSpec	Operates over the wavelength range of 0.6 to 5 micrometers with three observing modes.	Provider: ESA Lead Center: ESA Performing Center(s): N/A Cost Share Partner(s): ESA	N/A

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
MIRI	Operates over the wavelength range of 5 to 28 micrometers, providing imaging, coronagraphy, and spectroscopy.	Provider: ESA, University of Arizona, JPL Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Fine Guidance	Provides scientific target pointing information to the observatory's attitude control sub-system	Provider: Canadian Space Agency (CSA) Lead Center: CSA Performing Center(s): N/A Cost Share Partner(s): CSA	N/A
Launch vehicle and launch operations	Ariane 5	Provider: ESA Lead Center: ESA Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Ground control system and science operations and control center	Includes mission operations and science operations center	Provider: Space Telescope Science Institute (STScI) Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	Ground control system and science operations and control center

Project Risks

Risk Statement	Mitigation
If: If issues arise during environmental testing of OTIS, spacecraft, sunshield, or observatory, Then: This may delay completion of testing of the affected element, adding risk to achieving the June 2019 launch.	The project has established an environmental testing plan that includes testing at lower levels of assembly prior to integration and testing at higher levels of assembly, to reduce risk to testing at higher levels of assembly.

Acquisition Strategy

The project has awarded all major contracts.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Science and Operations Center	STScI	Baltimore, MD
NIRCam	University of Arizona; Lockheed Martin	Tucson, AZ Palo Alto, CA
Observatory	NGAS Ball Aerospace ITT/Exelis/Harris Alliant Techsystems	Redondo Beach, CA Boulder, CO Rochester, NY Edina, MN
Near Infrared Detectors	Teledyne Imaging Systems	Camarillo, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Apr 2010	CDR	Determined mission design is mature and recommended a more in-depth review of the integration and testing plan	May 2011
Quality	Test Assessment Team	Aug 2010	Evaluate plans for integration and testing. See the full report at http://www.jwst.nasa.gov/publications.html	The team recommended several changes to the test plan	N/A
Other	Independent Comprehensive Review Panel	Oct 2010	Determine the causes of cost growth and schedule delay on Webb, and estimate the launch date and budget, including adequate reserves	The report made 22 recommendations, covering several areas of management and performance	N/A
Other	The Aerospace Corporation	Apr 2011	Analysis of alternatives	Determined that Webb design was still the best value to achieve the primary scientific objectives of the mission	N/A

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	SRB	May 2011	Review technical, cost, and schedule plans	The SRB proposed rebaselined project technical, cost, and schedule plans and made recommendations to the Agency	Apr 2016
Performance	NASA Headquarters Office of Evaluation	Jun 2012	Replan assessment review	A review assessed progress against replan	N/A
Performance	SRB	Apr 2016	OTE/Integrated Science SIR	Completed	Aug 2016
Performance	SRB	Aug 2016	OTE/Integrated Science Pre-Environmental Review	Completed	July 2018
Performance	SRB	July 2018	Observatory SIR	TBD	TBD
Performance	SRB	TBD	ORR		

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**97.3**	**--**	**78.3**	**88.3**	**93.3**	**98.3**	**98.3**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

On August 17, 2017, the Laser Interferometer Gravitational-Wave Observatory detected gravitational waves from a neutron star collision. Within 12 hours, observatories had identified the source of the event within the galaxy NGC 4993, shown in this Hubble Space Telescope image, and located an associated stellar flare called a kilonova. Hubble observed that flare of light fade over the course of six days, as shown in these observations taken on August 22, 26, and 28 (insets).

One of NASA's most successful and long-lasting science missions, the Hubble Space Telescope, has beamed hundreds of thousands of images back to Earth, helping resolve many of the great mysteries of astronomy. The telescope helped scientists determine the age of the universe, the identity of quasars, and the existence of dark energy. Hubble launched in 1990 and is currently in an extended operations phase. The fifth servicing mission, in 2009, the last visit by a Space Shuttle crew, added new batteries, gyroscopes, and instruments to extend Hubble's life even further into the future.

April 24, 2017 marked the start of Hubble's 27th year in orbit. The observatory is currently in its most scientifically productive period.

EXPLANATION OF MAJOR CHANGES IN FY 2019

As in recent years, this budget reflects efficiencies realized by the project's excellent cost performance over the last few years. The change is consistent with operations that are more efficient and aligned with the observatory scientific program. Due to program efficiencies and appropriation of funds above the request for the past few years, the Hubble mission is carrying excess funding. This budget reflects use of excess funds from prior years, resulting in less resources requested in FY 2019. This adjustment is not expected to impact the workforce or science generated from the mission.

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

ACHIEVEMENTS IN FY 2017

Astronomers used data from HST to find evidence for a stratosphere on a planet orbiting another star. As on Earth, the planet's stratosphere is a layer where temperatures increase with higher altitudes, rather than decrease. To study the stratosphere of WASP-121b, scientists analyzed how different molecules in the atmosphere react to particular wavelengths of light, using Hubble's capabilities for spectroscopy. Water vapor in the planet's atmosphere, for example, would glow at particular wavelengths depending on the temperature of the water. These observations found the telltale glow of water in the atmosphere of WASP-121b, indicating the planet has water in its atmosphere and the water is within the stratosphere. The 2016 Senior Review of Operating Missions recommended continuing Hubble operations as long as the observatory remains highly capable scientifically. This budget supports that recommendation.

WORK IN PROGRESS IN FY 2018

In FY 2018 and beyond, NASA will support mission operations, systems engineering, software maintenance, ground systems support, and guest-observer science grants. Work continues on mission life extension initiatives, such as optimizing the use of Hubble’s gyroscopes and extending the lifetime of Hubble's instruments. NASA will announce Cycle 26 selections of GO proposals late in FY 2018.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

The Space Telescope Science Institute (STScI), which manages Hubble’s science program, will select Cycle 27 science observations. Similar to other recent competitions for Hubble observing time, NASA expects requested observational orbits to outnumber the available orbits by a factor of six to one, indicating that Hubble remains one of the world’s preeminent astronomical observatories.

Project Schedule

Date	Significant Event
May 2018	Release of Cycle 26 Call for Proposals
Aug 2018	Deadline for Cycle 26 Proposal Submissions
Nov 2018	Approximate date for Announcement of Cycle 26 selections
Jan 2019	Release of Cycle 27 Call for Proposals
Apr 2019	Deadline for Cycle 27 Proposal Submissions
Jul 2019	Approximate date for Announcement of Cycle 27 selections

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Formulation Agreement
Observatory Operation	Provides safe and efficient control and utilization of Hubble, maintenance and operation of its facilities and equipment, as well as creation, maintenance, and utilization of Hubble operations processes and procedures	Provider: Lockheed Martin Lead Center: Goddard Space Flight Center (GSFC) Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Science Management	Evaluates proposals for telescope time and manages the science program	Provider: STScI/Association of Universities for Research in Astronomy (AURA) Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): European Space Agency (ESA)	N/A

Acquisition Strategy

NASA competes all new Hubble research opportunities.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Observatory Operation	Lockheed Martin	Littleton, CO
Science Management	STScI/AURA	Baltimore, MD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Senior Review	2016	Evaluate efficiency and productivity of Hubble operations	Maximize Hubble science return and reliability within available resources	2019, 2022, 2025

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

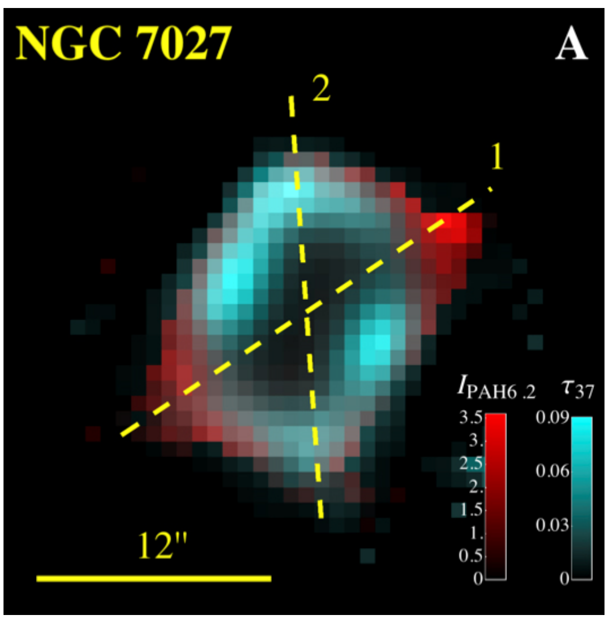
Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	FY 2020	Notional FY 2021	FY 2022	FY 2023
Total Budget	**85.2**	**--**	**74.6**	**39.8**	**16.6**	**0.0**	**0.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



Spatially resolved mid-infrared images of planetary nebula NGC 7027, located around 3,000 light years away in the constellation Cygnus, using the Faint Object Infrared Camera for the SOFIA Telescope (FORCAST). Planetary nebulae play a crucial role in the chemical evolution of our galaxy by expelling elements to the interstellar medium.

SOFIA is an airborne astronomical observatory that provides the international research community with access to infrared data unattainable from either ground-based or space telescopes. The images, spectra, and polarimetry have significant scientific value due to their coverage of mid- to far-infrared wavelengths. SOFIA investigates the cycle of material in the universe by peering through veils of dust to reveal physical phenomena hidden at other wavelengths. These wavelengths are key to unlocking questions regarding:

- Earliest phases of star birth;
- Formation of new planetary systems and implications for life-supportingconditions;
- Dust grain production;
- Space chemistries of life-sustaining molecules like water;
- Composition of comets and asteroids, which are ancient relics from our own solar system and provide clues to its beginnings; and
- Physical properties of planets both near and far (exoplanets), which provide context in understanding the habitability of our own Earth.

SOFIA officially entered the operations phase in May 2014.

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2019

This budget reflects efficiencies and lower-than-expected fuel costs realized by the project in the past few years. No impacts to science are expected in FY 2019. SOFIA will participate in the 2019 Astrophysics Senior Review. NASA will budget for the period of the mission extension if NASA grants SOFIA a mission extension following the senior review.

ACHIEVEMENTS IN FY 2017

NASA selected Cycle 5 proposals in January 2017 with a suite of seven instruments and observations began in early February. Researchers used SOFIA to solve questions on the formation and evolution of gas in clouds, local galaxies, and massive protostar nurseries, and investigated the role of density waves on star formation in grand design spirals.

The SOFIA project team conducted significant instrument commissioning and validation/verification support activities for the HAWC+ with improvement of the Adiabatic Demagnetization Refrigerator (ADR) hold time and upGREAT cryocooler, respectively.

In June through mid-August 2017, NASA conducted a seven-week deployment to the Southern Hemisphere to observe astronomical objects that are not visible in the skies from SOFIA's home base in California, followed by a scheduled period of aircraft maintenance. The SOFIA team shipped over 1000 cubic feet of Science Instrument equipment, weighing over 16.6 thousand pounds, to Christchurch New Zealand for the 2017 deployment.

SOFIA successfully flew (July 9-10) in the predicted path of the shadow (occultation) of a background star cast by MU69, the Kuiper belt object that is the target of the January 2019 flyby of New Horizons. The team also supported an occultation of Neptune's moon Triton, over the Atlantic Ocean, in early October 2017.

The High Resolution Mid Infrared Spectrometer (HIRMES) Instrument conducted a successful delta Preliminary Design Review in March 2017 and Critical Design Review in August 2017.

WORK IN PROGRESS IN FY 2018

SOFIA is nearing the completion of Cycle 5 observations, with the start of Cycle 6 observations commencing in February 2018. Cycle 6 has planned research hours allocated to Guest Investigators for programs covering a wide range of astronomical science areas.

HAWC+ will complete formal acceptance activities in January 2018. HAWC+ provides a new capability for SOFIA, a far-infrared polarimeter, which enables investigations into the roles magnetic fields play our galaxy. The development phase for the third-generation science instrument, the High Resolution Mid-Infrared Spectrometer (HIRMES) also continues in FY 2018.

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

Formulation	Development	Operations

The SOFIA project will release its Next-Generation Instrument Solicitation in January 2018 and they plan to down select for the instrument concept studies in July. The project will be conducting its down selection for the instrument development following the 2019 Senior Review. The planned schedule expects to infuse new capabilities on SOFIA no later than 2022.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

The third-generation SOFIA instrument HIRMES will complete its build and test phase with delivery to SOFIA in the first quarter of FY 2019. SOFIA will participate in the 2019 Senior Review. Whether or not NASA continues SOFIA operations including moving forward with development of the instrument is contingent on the result of the 2019 Senior Review.

Project Schedule

Date	Significant Event
Apr 2017	Release of Cycle 6 Call for Proposals
Nov 2017	Announcement of Selected Cycle 6 Investigations
Jun 2018	Summer Deployment Observation - New Zealand
Jan 2019	Next Generation SOFIA Instrument Proposals Due
Mar 2019	HIRMES Instrument Delivery
Apr 2019	SOFIA Senior Review
Aug 2019	Cycle 7 (GO) Proposals Due

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

Formulation	Development	Operations

Project Management & Commitments

The Ames Research Center (ARC) manages SOFIA.

Element	Description	Provider Details	Change from Formulation Agreement
Science Operations Center	Science Operations Center will solicit and select new investigations, schedule observations, and manage data acquisition and processing	Provider: ARC/ USRA Lead Center: ARC Performing Center(s): ARC Cost Share Partner(s): German Aerospace Center (DLR)/Deutsches SOFIA Institute (DSI)	N/A
Flight Operations	Flight crew, maintenance, and fuel	Provider: Armstrong Flight Research Center (AFRC)/Computer Sciences Corporation (CSC) DynCorp Lead Center: AFRC Performing Center(s): AFRC Cost Share Partner(s): DLR/DSI	N/A
Upgraded HAWC+	HAWC+ far-infrared camera to be upgraded with the addition of polarimetry capability and new state of the art detectors	Provider: Jet Propulsion Laboratory (JPL), GSFC Lead Center: ARC Performing Center(s): JPL, GSFC Cost Share Partner(s): N/A	N/A
SOFIA Program Management	Program management of flight and science	Lead Center: ARC	Yes
HIRMES	HIRMES will enable unique spectroscopic capability, providing a higher sensitivity and a higher spectral resolving power, from the 25 to 112 micrometer wavelength range, over any existing observatory.	Provider: GSFC Lead Center: ARC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

Formulation	Development	Operations

Acquisition Strategy

The project has awarded all major contracts. SOFIA awarded a new primary contract for its Science Mission Operations to the Universities Space Research Association (USRA) in March 2017.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Science & Mission Operations	USRA	Moffett Field, CA and Palmdale, CA
Platform	L3 Communications	Palmdale, CA
Cavity Door Drive System	Woodward MPC	Skokie, IL
Aircraft Maintenance Support	L3 Vertex Aerospace (under AFRC shared service contract)	Palmdale, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Mission Senior Review	N/A	Evaluate operations efficiency, merit of science case, and scientific productivity	Ranking of SOFIA science return and reliability within available resources will contribute to NASA decision on whether to extend SOFIA beyond FY 2019 into an extended mission phase	2019

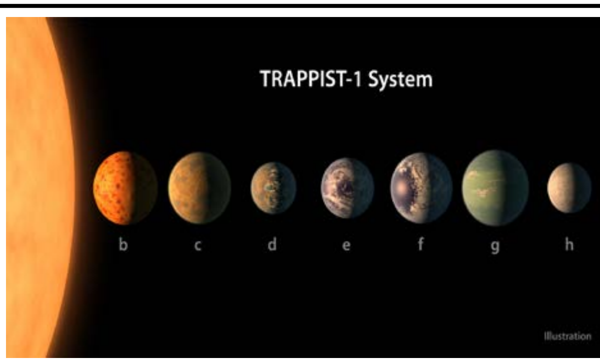
OTHER MISSIONS AND DATA ANALYSIS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Cosmic Origins Program Management	2.7	--	**2.7**	2.2	2.2	2.2	2.2
Cosmic Origins SR&T	12.8	--	**17.6**	16.8	18.4	18.4	18.4
Cosmic Origins Future Missions	0.0	--	**2.7**	2.2	28.7	43.8	43.8
SIRTF/Spitzer	11.0	--	**11.0**	8.0	3.0	0.0	0.0
Herschel	1.0	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**27.5**	--	**33.9**	**29.1**	**52.2**	**64.4**	**64.4**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



On February 22, 2017, NASA's Spitzer Space Telescope revealed the first known system of seven Earth-size planets around a single star and a new record for greatest number of habitable-zone planets found around a single star outside our solar system. All of these seven planets could have liquid water under the right atmospheric conditions, but the chances are highest with the three (e, f, and g) in the habitable zone.

Cosmic Origins Other Missions and Data Analysis funds the Spitzer Space Telescope, program management, supporting research and technology, and early studies of potential future Cosmic Origins missions.

Mission Planning and Other Projects

COSMIC ORIGINS PROGRAM MANAGEMENT

Cosmic Origins (COR) program management provides programmatic, technical, and business management, as well as program science leadership.

Recent Achievements

The COR program office continued to provide support with communications, by publishing theme Newsletters; enabling and facilitating community forums and meetings; and monitoring two of the large mission concept studies. This support has provided a unified and clear approach to the cosmic origins' goals and objectives.

OTHER MISSIONS AND DATA ANALYSIS

COSMIC ORIGINS STRATEGIC RESEARCH AND TECHNOLOGY (SR&T)

COR Strategic Research and Technology (SR&T) supports program-specific research and advanced technology development efforts, such as the Strategic Astrophysics Technology (SAT) solicitation issued in FY 2016. In addition, funding supports the study of future NASA space observatories.

Recent Achievements

The COR program released its updated Program Annual Technology Report based on the technical advances generated by the Strategic Astrophysics Technology (SAT) selected investigations. This report summarizes the status of technology development funded by the program in prior years and in FY 2017. This report describes the prioritization of future technology needs.

A copy of the report is available at
https://apd440.gsfc.nasa.gov/technology/patrs/documents/cor/2017_COR_PATR.pdf

This budget request supports a solicitation for industry for a future segmented-aperture Mirror Technology Development program. This new effort will develop end-to-end integrated telescope/coronagraph system-level engineering designs, modeling studies and associated testbed demonstrations.

The scientific community is actively engaged to lay the groundwork to mature mission concept studies and identify technology developments that will eventually provide inputs to the 2020 Astronomy and Astrophysics Decadal Survey. The four mission concept studies are Large Ultraviolet/Visible/Infrared Surveyor, Origins Space Telescope, Habitable Exoplanet Imaging Mission, and Lynx X-ray Surveyor. The four mission concept studies and the science case and notional telescope design and instrument studies began in FY 2016. These mission concepts will issue final reports during FY 2019.

COSMIC ORIGINS FUTURE MISSIONS

COR Future Missions funding supports studies of future mission concepts. COR Future Missions also supports the extension of COR missions following the Senior Review.

Recent Achievements

The COR scientific community is engaged in identifying meritorious and compelling science drivers that could lead to diverse mission concept studies and technology development that will inform the 2020 Astronomy and Astrophysics Decadal Survey.

Operating Missions

SPITZER

The Spitzer Space Telescope, launched in 2003 as the final element of NASA's series of Great Observatories continues in extended operations. Spitzer is an infrared telescope that uses two channels of the Infrared Array Camera instrument to study exoplanet atmospheres, early clusters of galaxies, near-Earth asteroids, and a broad range of other phenomena. Spitzer completed its cryogenic mission in

OTHER MISSIONS AND DATA ANALYSIS

FY 2009 and extended warm operations through FY 2016. The 2016 Senior Review of Operating Missions recommended continuing Spitzer operations until 2019, following launch of the James Webb Space Telescope (Webb). This budget supports that recommendation.

Recent Achievements

Spitzer continues to study exoplanets and exoplanetary systems. Recent Spitzer results show that large exoplanets comparable in size to Jupiter are more likely found around young stars that host such a debris disk than around naked, dust-free stars. This suggests that the presence of a debris disk would signal that a particular star would be a good candidate for future observatories, such as the James Webb Space Telescope, to search for exoplanets. Spitzer continues to make important connections between exoplanetary systems and the Solar System.

In another study, further analysis of Spitzer data on a planet called 55 Cancri e has provided new insights into this fascinating object. Previous analysis had shown that the surface temperature on this planet varies between 2,500 and 4,000 degrees Fahrenheit. It orbits very close to a bright star, which accounts for this high temperature. The new research suggests that the surface lies beneath a thick atmosphere, which could contain nitrogen, water, and even oxygen, the main important constituents of Earth’s atmosphere. Researchers also point out that it is too hot for water to be liquid on the surface of the planet and certainly too hot to support life as we know it. 55 Cancri e reminds us that the properties of exoplanets range far beyond those of the planets in the solar system and far beyond what even the most imaginative astronomers had anticipated. Nevertheless, studying these extreme systems continues to provide insights regarding the formation and evolution of our own familiar planets.

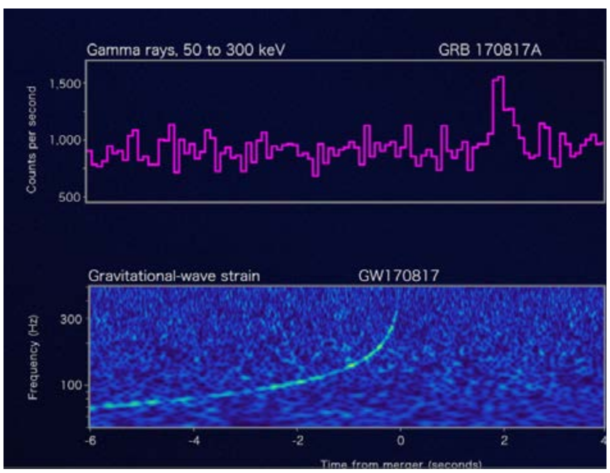
PHYSICS OF THE COSMOS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	FY 2020	Notional FY 2021	FY 2022	FY 2023
Other Missions and Data Analysis	106.2	--	**136.8**	139.1	113.3	108.3	105.0
Total Budget	**106.2**	**--**	**136.8**	**139.1**	**113.3**	**108.3**	**105.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



Fermi detected a burst of gamma rays (top panel) 3 seconds after LIGO registered the signal from the merger ("chirp", bottom panel) of two neutron stars in the local Universe. The detection of GW170817/GRB170817A marks the birth of multi-messenger astrophysics, where observations in the electromagnetic spectrum and gravitational waves combine to provide the most powerful probe yet of the Universe.

The universe can be viewed as a laboratory that enables scientists to study some of the most profound questions at the intersection of physics and astronomy. How do matter, energy, space, and time behave under extreme gravity? What is the nature of dark energy and dark matter? How did the universe grow from the Big Bang to its present size? The Physics of the Cosmos (PCOS) program incorporates cosmology, high-energy astrophysics, and fundamental physics projects that address central questions about the nature of complex astrophysical phenomena, such as black holes, neutron stars, dark matter and dark energy, cosmic microwave background, and gravitational waves.

The operating missions within the PCOS program continue to provide answers to these fundamental questions and more. Scientists using data from the Fermi mission discovered a gamma-ray burst associated with a gravitational wave source detected by the Laser Interferometry Gravitational Observatory (LIGO). A few days later, the Chandra X-ray Observatory detected the X-ray glow of the newly born source, from jets of matter produced after the merger of the two neutron stars. The gravitational wave, gamma-ray, and X-ray detections, together with optical and infrared detections with other NASA and ground-based telescopes, marks the advent of multi-messenger astrophysics, a powerful new window on the Universe.

Other PCOS missions, such as the X-ray Multi-Mirror Mission (XMM) continue to help astronomers progress in their understanding of some of the most mysterious phenomena, such as the condition of matter near supermassive black holes.

PHYSICS OF THE COSMOS

PCOS includes a vigorous program to develop the technologies necessary for the next generation of space missions to address the science questions of this program.

For more information, see: https://science.nasa.gov/about-us/smd-programs/physics-of-the-cosmos

EXPLANATION OF MAJOR CHANGES IN FY 2019

This budget includes a significant increase in supporting research and technology for future strategic and competed missions, enabled by redirecting funds made available due to the proposed termination of WFIRST.

OTHER MISSIONS AND DATA ANALYSIS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Physics of the Cosmos SR&T	23.3	--	**33.5**	41.1	39.4	34.1	30.9
Euclid	12.9	--	**20.2**	16.4	9.4	9.5	8.9
Physics of the Cosmos Program Management	2.6	--	**2.9**	2.4	2.4	2.4	2.4
Physics of the Cosmos Future Missions	0.1	--	**2.3**	3.4	3.7	4.0	4.4
Fermi Gamma-ray Space Telescope	12.5	--	**15.5**	14.0	0.0	0.0	0.0
Chandra X-Ray Observatory	50.7	--	**58.9**	58.4	58.4	58.4	58.4
XMM	3.5	--	**3.5**	3.5	0.0	0.0	0.0
Planck	0.6	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**106.2**	--	**136.8**	**139.1**	**113.3**	**108.3**	**105.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

This new image of the Crab Nebula combines data from five different telescopes: The VLA (radio) in red; Spitzer Space Telescope (infrared) in yellow; Hubble Space Telescope (visible) in green; XMM (ultraviolet) in blue; and Chandra X-Ray Observatory (X-ray) in purple.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Other Missions and Data Analysis supports PCOS SR&T, PCOS Program Management, PCOS Future Missions, Euclid, Fermi, Chandra, and XMM.

Mission Planning and Other Projects

PCOS SUPPORTING RESEARCH AND TECHNOLOGY

PCOS Supporting Research and Technology leads strategic technology development efforts, to prepare for the next generation of PCOS space missions. This includes program-specific research and advanced technology development efforts, such as the Strategic Astrophysics Technology (SAT) solicitation issued in FY 2016.

OTHER MISSIONS AND DATA ANALYSIS

NASA and ESA are continuing defining partnership for NASA's contribution to ESA's Athena mission, an X-ray observatory dedicated to high-resolution spectroscopy, and ESA's LISA mission, a space-based gravitational wave observatory. This project supports the technology development and pre-formulation activities necessary to contribute to the ESA missions.

This budget includes a significant increase in technology for future strategic and competed missions, enabled by redirecting funds made available due to the proposed termination of WFIRST.

Recent Achievements

The PCOS program released its updated Program Annual Technology Report. This report summarizes the status of technology development funded by the program in FY 2017 and describes the prioritization of future technology needs.

For more information, go to:
https://apd440.gsfc.nasa.gov/technology/patrs/documents/pcos/2017_PCOS_PATR.pdf

EUCLID

NASA is collaborating on Euclid, an ESA mission, selected as part of ESA's Cosmic Visions program in June 2012 and scheduled for launch in 2021. Euclid seeks to investigate the accelerated expansion of the universe, the so-called "dark energy," using a Visible Instrument and a Near Infrared Spectrometer and Photometer instrument, as well as ground-based data. The Euclid Consortium, comprised of over 1,200 scientists and engineers from over 50 institutes in Europe, the United States, and Canada, is responsible for development of the two instruments and the Science Data Centers. NASA contributes flight detector subsystems for the Near Infrared Spectrometer and Photometer instrument and a NASA Euclid Science Center that forms part of the Euclid Science Ground System. In exchange, NASA receives membership in the Euclid Science Team and Consortium and competed science opportunities for U.S. investigators.

Recent Achievements

Teledyne has delivered all 25-flight candidate detectors to NASA. NASA has completed acceptance vibration testing and performance testing for these 25 detectors sufficient to meet the delivery requirements of 16 flight units and four spares to ESA. NASA has also has completed the Cryo Flex Cables (CFC) which connect the detectors to the readout electronics known as Sensor Chip Electronics (SCE). To date NASA has delivered to ESA 9 flight grade detectors and CFCs. NASA plans to deliver remaining detectors and cables by early 2018. The SCEs have developed a significant problem during the testing at cryogenic temperatures. The lab testing has shown that the SCE is not fully able to communicate with the detectors. To investigate the problem NASA has formed a failure board. The proximate cause of this issue is a failure of Application Specific Integration Circuit (ASIC) packaging cracks while operating at cryogenic temperatures. Thermal stress likely causes this condition. NASA is developing an alternate design to remedy this problem, and a recovery plan for incorporation into ESA's mission development plan.

OTHER MISSIONS AND DATA ANALYSIS

PCOS PROGRAM MANAGEMENT

PCOS program management provides programmatic, technical, and business management, as well as program science leadership.

Recent Achievements

NASA entered into a letter of agreement with ESA to contribute to their Large 2 mission, Athena, an X-ray observatory dedicated to high-resolution spectroscopy. The details of the contribution are still under discussion. PCOS is leading the management of this contribution.

NASA is also collaborating with ESA on the LISA mission, a low-frequency gravitational wave observatory, and is contributing elements of the payload. NASA established a LISA Study Office, hosted by the PCOS Program, to manage the LISA technology development. NASA is preparing a Letter of Agreement with ESA.

PCOS FUTURE MISSIONS

PCOS Future Missions funding supports concept studies of future missions.

Recent Achievements

The PCOS program is engaging with the scientific community to lay the groundwork for design studies and technology development that will eventually provide inputs to the 2020 Astronomy and Astrophysics Decadal Survey.

Operating Missions

FERMI

The Fermi Gamma-ray Space Telescope explores extreme environments in the universe, from black holes to gamma-ray bursts, to expand knowledge of their high-energy properties. Fermi observations are answering long-standing questions across a broad range of topics, including solar flares, the origin of cosmic rays, and the nature of dark matter. NASA’s Fermi mission launched in June 2008 with contribution from international and the Department of Energy. Fermi entered extended mission operations in August 2013. The 2016 Senior Review of Operating Missions recommended continuing Fermi operations through FY 2019. This budget supports that recommendation.

Recent Achievements

For the first time, NASA scientists have detected light tied to a gravitational-wave event, caused by two merging neutron stars in the galaxy NGC 4993, located about 130 million light-years from Earth. On August 17, 2017, Fermi picked up a pulse of high-energy light from a powerful explosion and Fermi immediately communicated the status of the explosion to astronomers around the globe as a short gamma-ray burst. Just 1.7 seconds prior to Fermi’s detection, the National Science Foundation’s twin Laser Interferometer Gravitational-wave Observatory (LIGO) detectors caught a gravitational wave signal from the pair of smashing neutron stars that caused the gamma-ray burst. By combining information from Fermi, LIGO, and a worldwide network of telescopes observing in other wavelengths of light, scientists identified the source as a collision between two neutron stars – ultra-dense, crushed leftover cores of huge stars that exploded as supernovae long ago. In their final moments, this neutron star pair whipped around at nearly the speed of light, ripping at each other and churning out torrents of gravitational energy until they smashed together with a blast of gamma rays that lasted only two seconds. Another combined analysis of data from Fermi and the High Energy Stereoscopic System (H.E.S.S.), a ground-based observatory suggests the center of our Milky Way contains a "trap" that concentrates some of the highest-energy cosmic rays, among the fastest particles in the galaxy. The results imply that most of the more energetic cosmic rays populating the innermost region of our galaxy originate in active regions beyond the galactic center. These energetic cosmic rays will decelerate in the galaxy through interactions with gas clouds.

CHANDRA

Launched in 1999, Chandra is transforming our view of the universe with its high-quality X-ray images, providing unique insights into violent events and extreme conditions such as explosions of stars, collisions of galaxies, and matter around black holes. Chandra enables observations of clusters of galaxies that provide direct evidence of the existence of dark matter, and greatly strengthens the case for the existence of dark energy. Chandra observations of the remains of exploded stars, or supernovas, have advanced our understanding of the behavior of matter and energy under extreme conditions. Chandra also discovered and studied hundreds of supermassive black holes in the centers of distant galaxies. The 2016 Senior Review of Operating Missions recommended continuing Chandra operations as long as the observatory remains highly capable scientifically. This budget supports that recommendation.

Recent Achievements

Chandra made four X-ray observations of the gravitational wave event detected by LIGO and Fermi, the first a non-detection and the other three, nine days later, showing a significant source coincident with the optical position of gravitational wave event. The detection of X-rays demonstrates that neutron star mergers can form powerful jets streaming out at near light speed. The delay was a result of our viewing angle, and it took time for the jet directed toward Earth to expand into our line of sight. Astronomers using Chandra have found evidence for a star that whips around a black hole about twice an hour, the tightest orbital dance ever witnessed for a likely black hole and a companion star. New Chandra data of this system show that it changes in X-ray brightness in the same manner every 28 minutes, which is likely the length of time it takes the companion star to make one complete orbit around the black hole at only about 2.5 times the separation between the Earth and the Moon. Chandra has discovered a mysterious flash of X-rays in the deepest X-ray image ever obtained. The X-ray source, located in a region of the sky known as the Chandra Deep Field-South, has remarkable properties. Prior to October 2014, this source not detected in X-rays, but then it erupted and became at least a factor of 1,000 brighter in a few hours. After about a day, the source had faded completely below the sensitivity of Chandra. Two of the three main possibilities to explain the X-ray source invoke gamma-ray burst events, which are jetted explosions triggered either by the collapse of a massive star or by the merger of a neutron star with another neutron star or a black hole. New Chandra observations revealed five pairs of supermassive black holes, each containing millions of times the mass of the Sun. These black hole couples formed when two galaxies collided and merged with each other, forcing their supermassive black holes close together. Before this study, scientists knew of fewer than ten confirmed pairs of growing black holes. The Chandra observations reveal how common supermassive black hole pairs are and help in predicting the signals for gravitational wave observatories

OTHER MISSIONS AND DATA ANALYSIS

X-ray Multi-Mirror Mission (XMM)

XMM is an ESA-led mission with substantial NASA contributions. The telescope launched in December 1999 and provides unique data for studies of the fundamental processes of black holes and neutron stars. XMM studies the evolution of chemical elements in galaxy clusters and the distribution of dark matter in galaxy clusters and elliptical galaxies. The 2016 Senior Review of Operating Missions recommended continuing operations through FY 2019. This budget supports that recommendation.

Recent Achievements

During the past year, a new study using data from NASA's Chandra X-ray Observatory and ESA's XMM suggests X-rays emitted by a planet's host star may provide critical clues to how hospitable a star system could be. Researchers looked at the X-ray brightness from 24 stars with masses similar to the Sun or less, each at least one billion years old. The study has revealed that stars like the Sun calm down surprisingly quickly after a turbulent youth, which has positive implications for the long-term habitability of planets orbiting such stars. Using a trio of X-ray telescopes from XMM, Chandra and Swift, astronomers found evidence for a tidal disruption event, where the tidal forces due to the intense gravity from a black hole can destroy an object — such as a star — that wanders too close. A giant black hole ripped apart a star and then gorged on its remains for about a decade. This is more than ten times longer than any observed episode of a star's death by black hole. XMM focused on a black hole for 17 days straight, revealing the extremely variable nature of the winds. Using these most detailed observations yet of such an outflow, coming from an active galaxy, scientists concluded that the winds recorded from the black hole reach 71,000 km/s, or about 0.24 times the speed of light, putting it in the top 5% of fastest known black hole winds.

EXOPLANET EXPLORATION

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Other Missions and Data Analysis	152.6	--	**52.4**	44.5	44.6	44.4	44.9
Total Budget	**152.6**	**--**	**52.4**	**44.5**	**44.6**	**44.4**	**44.9**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

The Kepler-90 planetary system has a similar configuration to our solar system with small planets found orbiting close to their star, and the larger planets found farther away. The pattern we see around Kepler-90 could be evidence of that same process happening in this system.

Humankind stands on the threshold of a voyage of unprecedented scope and ambition, promising insight into timeless questions: Are we alone? Is Earth unique, or are planets like ours common? One of the most exciting new fields of research within the NASA Astrophysics portfolio is the search for planets, particularly Earth-like planets, around other stars.

Since the discovery of the first exoplanets in the mid-1990s, astronomers have discovered and confirmed over 3,500 planets orbiting stars of all shapes and sizes in our galaxy. At first, most of the planets discovered were so-called “Hot Jupiters”— gas giants similar in size to the planet Jupiter, but orbiting much closer to their parent stars. However, analysis of the complete Kepler data set suggests that smaller planets — with sizes in the Earth-to-Neptune range — are actually more common. Rocky planets in the habitable zone of their parent stars appear to be common. NASA’s Exoplanet Exploration program is advancing along a path of discovery leading to a point where scientists can directly study the atmospheres and surface features of habitable, rocky planets, like Earth, around other stars in the solar neighborhood.

In the future, NASA aims to develop systems that will allow scientists to take the pivotal step from identifying an exoplanet as Earth-sized to determining whether it is truly Earth-like, and possibly even detecting if it bears the fingerprints of life. Such an ambitious goal includes significant technological challenges. An important component of the Exoplanet Exploration effort is a robust technology development program with the goal of enabling a future direct detection and characterization mission.

For more information, go to https://exoplanets.nasa.gov/.

EXOPLANET EXPLORATION

EXPLANATION OF MAJOR CHANGES IN FY 2019

Given its significant cost and higher priorities within NASA, the budget proposes the termination of the WFIRST mission. Development of WFIRST would have required a significant funding increase in FY 2019 and future years, with a total cost of more than $3 billion, which cannot be accommodated within a reduced Astrophysics top line. Some of the previously planned FY 2019-2023 WFIRST funding is redirected towards other priorities of the astrophysics community, including competed astrophysics missions and research.

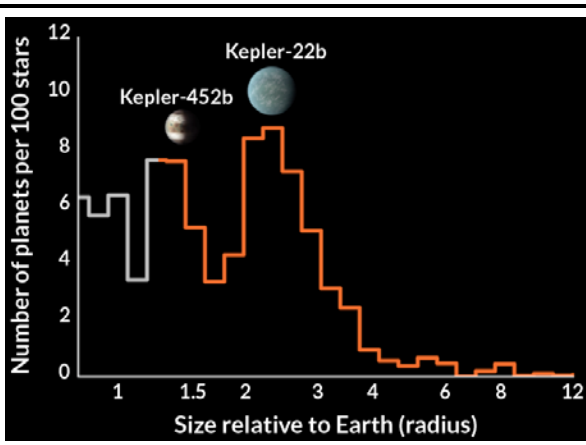
OTHER MISSIONS AND DATA ANALYSIS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
WFIRST	105.0	--	**0.0**	0.0	0.0	0.0	0.0
Exoplanet Exploration SR&T	21.2	--	**28.5**	27.2	28.4	28.3	28.3
Exoplanet Exploration Program Management	5.9	--	**8.0**	7.8	8.0	7.9	8.3
Exoplanet Exploration Future Missions	0.9	--	**1.5**	1.6	1.4	1.2	1.0
Keck Operations	6.1	--	**6.5**	6.7	6.9	7.0	7.2
Large Binocular Telescope Interferometer	2.6	--	**0.0**	0.0	0.0	0.0	0.0
Kepler	11.0	--	**7.9**	1.3	0.0	0.0	0.0
Total Budget	**152.6**	**--**	**52.4**	**44.5**	**44.6**	**44.4**	**44.9**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



Small planets come mainly in two sizes; Super-Earths or Mini-Neptunes. The Kepler team announced this result on June 19, 2017 at NASA's Ames Research Center. The Keck Observatory obtained data on exoplanet masses to confirm this discovery.

Mission Planning and Other Projects

Wide-Field Infrared Survey Telescope (WFIRST)

WFIRST would have explored the nature of dark energy, in addition to completing the exoplanet census through a gravitational microlensing survey. It also would have directly detected exoplanets through a coronagraph technology demonstration.

Recent Achievements

WFIRST is currently in its concept and technology development phase, having entered formulation in February 2016. Two aerospace companies have completed formulation studies for the Wide Field Instrument Opto-Mechanical Assembly, a critical element of the mission payload system. The telescope contractor has completed environmental tests to demonstrate the suitability of key elements of the existing telescope hardware at WFIRST's cool operating temperature. Coronagraph instrument development continues to make excellent progress, with the developmental instrument demonstrating very deep contrast across a wide wavelength band.

OTHER MISSIONS AND DATA ANALYSIS

In October 2017, NASA received the findings of the WFIRST Independent External Technical/Management/Cost Review (WIETR), conducted by a blue-ribbon panel of experts from outside the Agency. The WIETR found that the mission's scope and requirements were inconsistent with the WFIRST life-cycle cost and budget profile set in the Agency's management agreement, and recommended that NASA reduce the mission scope to fit within the management agreement.

The budget proposes termination of the WFIRST mission in FY 2019 given its significant cost and higher priorities within NASA. Development of the mission would have required a significant funding increase in 2019 and future years, which cannot be accommodated within a reduced Astrophysics top line. Some of the previously planned FY 2019-2023 WFIRST funding is redirected towards future competed astrophysics missions and research, consistent with priorities outlined in the Decadal Survey.

EXOPLANET EXPLORATION STRATEGIC RESEARCH AND TECHNOLOGY

Exoplanet Exploration Strategic Research and Technology supports program-specific scientific research, in addition to technology development activities that support and enable future Exoplanet Exploration missions.

NASA currently supports ten competitively selected exoplanet technology development projects involving researchers across the Nation. The selected technology development projects all focus on advancing technologies for separating the feeble reflected light of an exoplanet from the overwhelming glare of its parent star, revealing clues to the planet's nature. Those technologies will one day enable the ultimate goal of NASA's Exoplanet Exploration Program: a future mission capable of imaging and measuring the spectra of habitable, Earth-like exoplanets in the solar neighborhood. Precision radial velocity technologies will enable better measurements of exoplanet masses. These precision radial velocity measurements, in conjunction with the transit photometric information that can provide the exoplanet radii, will result in the determination of exoplanet densities and structures before possible follow-ups in the search of chemical biomarkers of life.

Recent Achievements

Coronagraphs and starshades are enabling technologies for the direct detection of exoplanets around stars. They block the light from the stars and, thus, make possible the detection of planets orbiting the parent star. NASA could use this technology in possible future missions, enabling direct imagining of exoplanets and the search for spectral bio signatures. The Wide-Field Infrared Survey Telescope (WFIRST) coronagraph remains on schedule to execute its groundbreaking technology demonstration on the WFIRST observatory. In addition, NASA is assessing new coronagraph techniques for their application to the segmented optics of future large telescopes. The NASA starshade team, with membership from government, academia, and industry, has made excellent progress on defining a detailed plan for ground-based demonstration of the five critical starshade technology elements by the early 2020's.

The NASA and NSF partnership to develop a new precision radial velocity instrument for the WIYN telescope is progressing well, with commissioning of the new instrument on schedule for 2019.

This budget includes a significant increase in supporting research and technology for future strategic and competed missions, enabled by redirecting funds made available due to the proposed termination of WFIRST.

OTHER MISSIONS AND DATA ANALYSIS

EXOPLANET EXPLORATION PROGRAM MANAGEMENT

Exoplanet Exploration program management provides programmatic, technical, and business management, as well as program science leadership. Program management coordinates, supports, tracks the progress of the program's numerous technology development tasks, and oversees the program's portfolio of projects.

Recent Achievements

Scientists have confirmed approximately 3,500 exoplanets among the approximately 6,100 candidates currently catalogued. Current estimates indicate that perhaps one in ten stars host rocky planets that exist in orbits where water may flow freely upon their surface. The program is managing design studies of mission opportunities. The program is also engaging with the scientific community on design studies and technology development that will eventually provide inputs to the 2020 Astronomy and Astrophysics Decadal Survey.

EXOPLANET EXPLORATION FUTURE MISSIONS

Exoplanet Exploration Future Missions funding supports the execution of the exoplanet mission science and technology definition teams, and ultimately the formulation, development, and implementation of a future Exoplanet Exploration flight mission.

Recent Achievements

Community-based science and technology teams continue to be engaged to develop mission concepts and technology development plans. To prepare for the next decade, NASA is studying the scientific merits of exoplanet missions in both the probe (medium) and large classes.

Operating Missions

KECK OPERATIONS

Keck Operations is the NASA portion of the Keck Observatory partnership. NASA uses its share of observing time in support of Astrophysics and Planetary Science programs. The project allocates observing time for NASA astrophysics science goals, as well as solar system objects and direct space mission support. Observation time is competed, selected, and managed by the NASA Exoplanet Science Institute. NASA is partner for one-sixth of the observing nights with the W.M. Keck Observatory (WMKO) for both 10-meter telescopes, the largest optical telescope pair in the world. The Keck Observatory Archive (KOA), managed by the NASA Exoplanet Science Institute, ingests and curates existing and new data from the Keck Observatory.

Recent Achievements

The large number of proposals submitted continues to demonstrate strong demand for NASA observing nights. For example, in semester 2017B, scientists submitted 75 proposals requesting 109.13 nights, yielding an overall oversubscription of 3.4 for both Keck telescopes. The astronomical community actively uses the KOA. Currently, 14 percent of WMKO publications cite the archive as the source of the data. The annual growth is attributable to the availability of more than 10 of instruments in KOA covering 25 years of the "Keck Sky."

NASA's current cooperative agreement with the W.M. Keck Observatory expires in 2018. On September 7, 2017, NASA announced the approval of the five-year renewal of the cooperative agreement after issuing a call for proposals, conducting an evaluation and considering the strategic value that the Keck observatory provides to NASA missions. This new Cooperative Agreement will run from March 1, 2018 until February 28, 2023.

LARGE BINOCULAR TELESCOPE INTERFEROMETER

The Large Binocular Telescope Interferometer (LBTI) is the NASA portion of the Large Binocular Telescope partnership. Engineers and scientists designed the LBTI to allow high contrast, high spatial resolution infrared imaging of dust clouds around nearby stars. The system surveys nearby stars for dust and debris disks that may hamper the detection of planets around those stars. This information will be crucial for designing future space observatories capable of detecting and characterizing those planets by direct imaging.

Recent Achievements

LBTI images the dust and planets around nearby stars at infrared wavelengths using a technique called *Nulling Interferometry*. These observations provide a first look at some of the most interesting exoplanetary systems in the solar neighborhood. LBTI is currently executing the Hunt for Observable Signatures of Terrestrial Systems (HOSTS) survey.

At a NASA HQ review on July 28, 2017, LBTI reported observing 26 out of 35 stars, which amounts to 74 percent completion of the HOSTS survey. The data suggest that dust disks around stars are not an obvious hindrance to future exoplanet imaging missions. The LBTI project will conclude the planned HOSTS survey observations during FY 2018.

KEPLER

Kepler, launched in March 2009, surveys stars in the local region of the Milky Way galaxy to detect and characterize rocky planets in or near the habitable zone of their host star. The habitable zone encompasses the distances from a star where liquid water can exist on a planet's surface. As time progresses, smaller planets with longer orbital periods emerge from the data.

In June 2014, NASA approved Kepler to enter a new phase of operations, called K2, in which the spacecraft observes along the ecliptic plane, opening up new possibilities for discovery. Both the 2014 and 2016 Senior Reviews of Operating Missions favorably reviewed the K2 operating mode.

The original phase of the mission ended September 30, 2017 with the delivery of all of the data acquired during this fully calibrated and vetted data to the Mikulski Archives at Space Telescope (MAST) for future use by the astronomical community. The extended (K2) phase of the mission will operate until the on-board fuel is depleted, estimated to occur in mid-CY2018. NASA continually monitors the estimate of the remaining fuel reserve. The 2016 Senior Review of Operating Missions recommended continuing the

K2 phase of the Kepler mission through the exhaustion of on-board fuel. This budget supports that recommendation.

Recent Achievements

On March 12, 2017, Kepler released the data of the recently completed campaign 12, which included observations of the nearby multiple planetary system TRAPPIST-1. This is a system with previously observed three exoplanets, but subsequent Spitzer observations detected four additional Earth-size planets in this system. The Kepler data taken over 79 days of observations of TRAPPIST-1 confirmed all seven planets, determined a more accurate orbital period for the seventh planet of 18.7 days, a radius of 0.715 of the Earth radius, and a rotation period of 3.3 days for the star. Owing to the proximity and size of this system, Webb should be able to discern the properties of the atmospheres of this intriguing multiple planetary system.

NASA held a new media briefing on June 19, 2017, to announce the latest planet candidate results from the primary Kepler mission. After four years of continuous observation of the Cygnus field, NASA reported 219 new planet candidates, of which 10 are less than twice the size of the Earth and orbit in the habitable zone. With these new discoveries, Kepler has identified more than 4,500 planet candidates orbiting other stars and confirmed about 2,337 as planets. Overall, Kepler has discovered about 84 percent of all candidates and confirmed exoplanets until now.

Within the realm of stellar astrophysics, on August 25, 2017, Kepler released an important discovery in the Seven Sisters as part of the Pleiades cluster. Using a new algorithm to enhance observations, an observing team performed the most detailed study yet of the variability of these stars. Kepler searches for planets orbiting distant stars by looking for the dip in brightness as the planets pass in front. Kepler also enables asteroseismology, studying the structure and evolution of stars as revealed by changes in their brightness. Most of the seven stars are revealed to be slowly pulsating B stars, a class of variable star in which the star's brightness changes with daylong periods. The frequencies of these pulsations are key to exploring some of the poorly understood processes in the core of these stars.

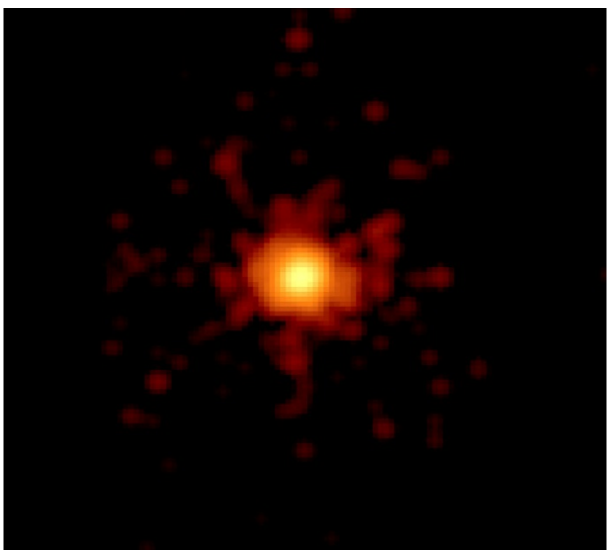
Astrophysics Explorer

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	FY 2020	Notional FY 2021	FY 2022	FY 2023
Transiting Exoplanet Survey Satellite (TESS)	74.0	36.9	**27.5**	3.8	0.0	0.0	0.0
Other Missions and Data Analysis	50.0	--	**218.1**	362.8	394.0	401.6	412.8
Total Budget	**124.1**	**--**	**245.6**	**366.5**	**394.0**	**401.6**	**412.8**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



A titanic burst of energy from a dying star 13 billion light years away has been spotted (center) from Earth. The caption of the figure needs to identify the mission and the science.

The Astrophysics Explorer program provides frequent flight opportunities for world-class astrophysics investigations using innovative and streamlined management approaches for spacecraft development and operations. The program is highly responsive to new knowledge, new technology, and updated scientific priorities by launching smaller missions that can be conceived and executed in a relatively short development cycle. NASA selects new missions based on an open competition of concepts solicited from the scientific community. The program emphasizes the accomplishments of missions under the control of the scientific research community within constrained mission life-cycle costs.

Medium-Class Explorers (MIDEX) missions cost up to $400 million in total, including launch services. Small Explorers (SMEX) may cost about half that total. Explorer missions of opportunity (MO) have a total NASA cost of under $75 million and may be of several types. The most common type of MOs are those that will fly on a non-NASA space mission. NASA conducts these missions on a no-exchange-of-funds basis with the organization providing the spacecraft for the mission. Other possible types are new science missions using existing spacecraft and small complete missions. NASA intends to solicit proposals for MOs associated with each AO issued for MIDEX and SMEX investigations.

For more information on Explorer missions, see: http://explorers.gsfc.nasa.gov/missions.html.

ASTROPHYSICS EXPLORER

EXPLANATION OF MAJOR CHANGES IN FY 2019

This budget includes a significant increase in FY 2019, enabled by redirecting funds made available due to the proposed termination of WFIRST. This increased funding will potentially enable the start of a competed probe-class mission.

ACHIEVEMENTS IN FY 2017

The Neutron-star Interior Composition Explorer (NICER) launched on a SpaceX Falcon 9 on June 3, 2017. NICER was installed on the external logistics carrier of the International Space Station and has completed in-orbit checkout. The Transiting Exoplanet Survey Satellite (TESS) mission successfully completed its System Integration Review (SIR) in July 2017, and began Phase D, the system assembly, integration and test, launch and checkout phase of implementation. In June 2017, NASA released the first (Cycle 1) TESS General Investigator solicitation, an opportunity for the broader scientific community to participate in target selection and analysis of observations during the first year of mission operations. In January 2017, NASA selected the Imaging X-ray Polarimetry Explorer (IXPE) mission to begin preliminary design and technology completion activities. IXPE will be launched into a low inclination, low Earth orbit for a two-year mission beginning in April 2021. In March of 2017, NASA selected the GUSTO balloon payload as a Mission of Opportunity to launch on a high-altitude stratospheric balloon from McMurdo, Antarctica in 2021 for approximately 100 days. NASA and JAXA jointly agreed to participate in the X-ray Astronomy Recovery Mission (XARM), in order to recover the soft X-ray spectroscopic capability lost with the Hitomi mission in March 2016. The NASA contribution to XARM completed its System Requirements Review in September 2017. NASA selected three MIDEX proposals and three MO proposals for competitive Phase A concept studies.

WORK IN PROGRESS IN FY 2018

NICER is operational and has successfully observed over 50 celestial targets. TESS will be ready for launch no later than June 2018. The scientific community submitted more than 140 proposals in response to the first TESS General Investigation (GI) solicitation. NASA will review these and select winning proposals before launch, to inform planning for the first year of mission operations. IXPE is now in Phase B after successful completion of the System Requirements Review in September 2017. In the last quarter of FY 2018 IXPE will pass its Key Decision Point (KDP)-C review to enter into Phase C, the final design and fabrication activities phase of development. GUSTO completed requirements tailoring to enter Phase B formulation in January 2018. NASA expects its contribution to XARM to pass reviews to enter Phase C during FY 2018. In summer 2018, NASA will receive and review the MIDEX and MO Phase A mission concept studies.

Later this fiscal year, NASA will begin discussions with the astrophysics community to formulate a plan for future competed missions (Explorers and probe-class).

KEY ACHIEVEMENTS PLANNED FOR FY 2019

TESS will continue its first year of operations. NASA will release a solicitation for the second TESS General Investigation program. IXPE will be in Phase C/D, the final design and fabrication activities phase of development. GUSTO will continue payload development leading up to the Integrated Baseline Review and Critical Design Review. The NASA contributions to XARM will continue fabrication. In the first half of FY 2019 NASA will select MIDEX and MO investigations to proceed into implementation, based on review of the Phase A mission concept studies.

NASA will release an Announcement of Opportunity for Astrophysics Small Explorers and Missions of Opportunity. If the President's Budget proposal for Astrophysics is enacted, including the termination of WFIRST and increase to the Astrophysics Explorer program, NASA will also issue an Announcement of Opportunity for a probe-class mission.

Program Schedule

Date	Significant Event
Feb 2019	Down select one MIDEX and one MO mission for implementation
Mar 2019	AO announcement of SMEX and MO opportunity to propose
Feb 2020	SMEX and Explorer MO KDP-A
Sep 2021	AO announcement for MIDEX and MO opportunity to propose
Feb 2022	Down select one SMEX and one MO mission for implementation
Aug 2022	MIDEX and Explorer MO KDP-A

Program Management & Planned Cadence

The Astrophysics and Heliophysics Explorer Programs are both coordinated sets of uncoupled missions, wherein each mission is independent and has unique science. The Programs share a common program office at GSFC and a common management structure. The Explorer program manager resides at GSFC, reporting functionally to the Center Director and programmatically through the Astrophysics and Heliophysics Division Directors to the Associate Administrator for SMD.

This submit brings the Astrophysics Explorer Program into alignment with the Decadal Survey's recommendation of a two-to-three year mission cadence.

Acquisition Strategy

NASA selects all Explorer missions through competitive AOs.

ASTROPHYSICS EXPLORER

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Independent Review	SRB	Oct 2014	Assess performance of program	Successful	Sep 2019

TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

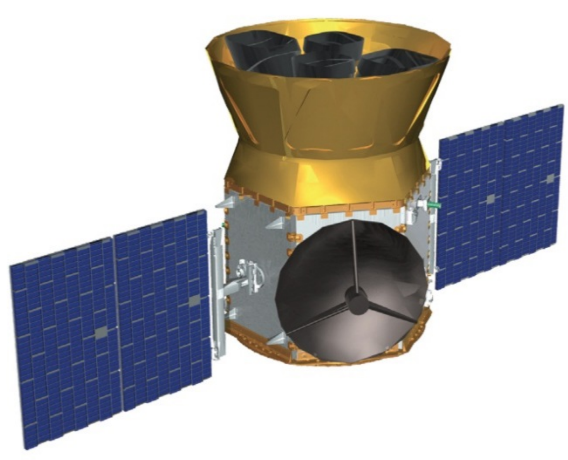
Formulation	Development	Operations

FY 2019 Budget

		Actual	CR	Request	Notional					
Budget Authority (in $ millions)	**Prior**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**	**FY 2023**	**BTC**	**Total**
Formulation	27.1	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	27.1
Development/Implementation	187.1	74.0	20.3	**0.0**	0.0	0.0	0.0	0.0	0.0	281.4
Operations/Close-out	0.0	0.0	16.6	**27.5**	3.8	0.0	0.0	0.0	0.0	47.9
2018 MPAR LCC Estimate	**214.2**	**74.0**	**36.9**	**27.5**	**3.8**	**0.0**	**0.0**	**0.0**	**0.0**	**356.4**
Total Budget	**214.2**	**74.0**	**36.9**	**27.5**	**3.8**	**0.0**	**0.0**	**0.0**	**0.0**	**356.4**
Change from FY 2018				**-9.4**						
Percentage change from FY 2018				**-25.5%**						

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



The TESS mission will detect small planets with bright host stars in the solar neighborhood, so that other telescopes can perform detailed characterizations of the planets and their atmospheres.

PROJECT PURPOSE

TESS will carry out the first space-borne all-sky exoplanet survey, searching for transiting exoplanets around 200,000 of the brightest and nearest stars to the Earth. TESS' three-year prime mission lifetime includes two years of TESS observations with an additional third year of follow-up ground-based observations.

To accomplish its mission, TESS will use an array of four wide-field cameras that together cover 400 times as much sky as any previous mission, including Kepler. It may discover approximately 30 Earth sized planets, 200 Super-Earth sized planets, and 400 sub-Neptune sized planets around other stars in the solar neighborhood.

With TESS, it will be possible to study the masses, sizes, densities, and orbits of small exoplanets, including a sample of rocky worlds in the habitable zones of their host stars. Whereas Kepler taught us about the demographics of exoplanetary systems. TESS will discover many of the closest exoplanetary systems to the Earth and provide prime targets for further characterization by the James Webb Space Telescope (Webb) as well as other future large ground-based and space-based telescopes.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

PROJECT PARAMETERS

NASA will launch TESS into a high Earth elliptical orbit. TESS will make observations in the visible and near-infrared spectrum, utilizing four telescopic charge-coupled device (CCD) cameras. TESS will obtain imagery from both northern and southern hemispheres of the sky. TESS will orbit the Earth every 13.7 days, and will downlink, via Ka-band, the data it has collected over a period of approximately five hours each orbit. TESS will be a three axis-stabilized spacecraft using both momentum wheels and hydrazine thrusters.

ACHIEVEMENTS IN FY 2017

TESS successfully completed the Systems Integration Review (SIR) in July 2017, the KDP-D review in August 2017, and is currently in Phase D. In June of 2017, NASA released the first (Cycle 1) TESS General Investigation (GI) solicitation. The Cycle 1 GI solicitation provides the opportunity for the broader scientific community to participate in target selection and analysis of observations conducted during the first year of mission operations.

WORK IN PROGRESS IN FY 2018

The project has started Phase D, the completion of the TESS Observatory integration and testing, and the delivery of TESS to KSC and launch no later than June 2018. The science community submitted more than 140 proposals in response to the TESS Cycle 1 GI solicitation. NASA will conduct a review of those proposals and make selections during the first half of FY2018 so that the results can feed into planning the first year of mission operations.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

TESS flight operations will continue. NASA will issue a solicitation for Cycle 2 GI proposals and review and select proposals in time to feed into planning for the second year of TESS mission operations.

TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

NASA plans to launch TESS no later than June 2018 to begin a three-year prime mission.

Milestone	Confirmation Baseline Date	FY 2019 PB Request
CDR	Apr 2015	Dec 2015
SIR	Oct 2016	July 2017
Start Phase D	Nov 2016	August 2017
Operations Readiness Review (ORR)/Flight Readiness Review (FRR)	Dec 2017	Feb 2018
Launch Readiness Date (LRD)/Initial Operating Capability (IOC)/IC	Jun 2018	Jun 2018
Start Phase E	Aug 2018	Aug 2018
End Prime Mission	Aug 2021	Aug 2021

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2015	323.2	>70	2018	281.4	-13	LRD	Jun 2018	Jun 2018	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**323.2**	281.4	-41.8
Aircraft/Spacecraft	43.0	66.1	23.1
Payloads	23.2	67.9	44.7
Systems I&T	3.7	4.7	1.0
Launch Vehicle	114.1	87.4	-26.7
Ground Systems	16.7	12.3	-4.4
Science/Technology	7.5	6.2	-1.3
Other Direct Project Costs	115.0	36.8	-78.2

Project Management & Commitments

GSFC is responsible for Project Management.

Element	Description	Provider Details	Change from Baseline
Instrument	Visible-IR telescopic CCDs detectors	Provider: Massachusetts Institute of Technology (MIT) Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	None
Spacecraft Bus	LEO Star three-axis stabilized spacecraft bus	Provider: Orbital ATK Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	None
Launch Vehicle	Launch Vehicle	Provider: Space Exploration Technologies Corporation (SpaceX) Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	None

TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: the TESS observatory, integration and testing is not successfully completed Then: the TESS LRD will need to slip.	The TESS Project will respond to any issues as required during Integration and testing, and coordinate into the KSC Launch Services Program as required.

Acquisition Strategy

NASA selected the mission through a competitive AO.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Spacecraft Bus	Orbital ATK	Dulles, VA
Launch Vehicle	SpaceX	Hawthorne, CA
Instrument	MIT	Boston, MA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Feb 2014	SRR	Successful	Preliminary Design Review (PDR)
Performance	SRB	Sep 2014	PDR	Successful	CDR
Performance	SRB	Start Aug 2015/ completed Dec 2015	CDR/delta CDR	Successful	SIR
Performance	SRB	July 2017	SIR	Successful	Launch Readiness Review (LRR)
Performance	SRB	Feb 2018	ORR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Galactic/Extragalactic ULDB Spectroscopi	2.4	--	**13.2**	11.6	7.5	3.5	0.0
Imaging X-Ray Polarimetry Explorer	11.3	--	**65.9**	67.3	40.7	5.0	4.2
Astrophysics Explorer Future Missions	15.2	--	**112.1**	262.9	334.1	385.2	398.5
Astrophysics Explorer Program Management	6.1	--	**10.9**	8.5	11.8	7.9	10.1
Neutron Star Interior Composition Explor	4.6	--	**2.4**	0.0	0.0	0.0	0.0
Swift	5.5	--	**5.4**	5.5	0.0	0.0	0.0
Nuclear Spectroscopic Telescope Array	5.0	--	**8.3**	7.0	0.0	0.0	0.0
Total Budget	**50.0**	**--**	**218.1**	**362.8**	**394.0**	**401.6**	**412.8**

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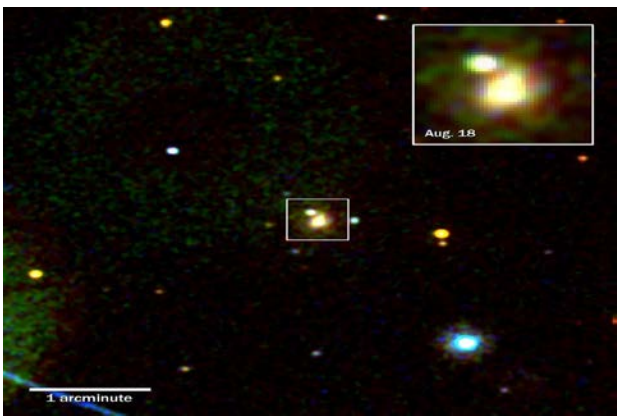

Swift's ultraviolet image of the galaxy NGC 4993 (box); the bright blob above the galaxy is the explosive result of two neutron stars merging. The picture combines images through three ultraviolet filters. It was taken about 15 hours after gravitational waves from the explosion and a burst of gamma-rays arrived at Earth on August 17, 2017.

Astrophysics Explorers Other Missions and Data Analysis includes funding for small missions in formulation and development (GUSTO, IXPE, XARM), operating missions (NICER, NuSTAR, Swift), and funding for future mission selections and program management functions.

Mission Planning and Other Projects

GALACTIC/EXTRAGALACTIC ULDB SPECTROSCOPIC TERAHERTZ OBSERVATORY (GUSTO)

In March of 2017, NASA's Astrophysics Explorers Program selected the GUSTO balloon payload as a Mission of Opportunity. GUSTO will launch on a high-altitude stratospheric balloon from McMurdo, Antarctica in 2021 for approximately 100 days. GUSTO's telescope and Terahertz heterodyne array receivers will provide the spectral and spatial resolution needed to study the interstellar medium. The GUSTO mission will provide the first complete study of all phases of the stellar life cycle, from the formation of molecular clouds, through star birth and evolution, to the formation of gas clouds and the reinitiation of the cycle. During flight, the GUSTO payload will conduct its scientific observation while tracking the prevailing stratospheric winds at the float altitude of 33.5 km. GUSTO completed all requirements tailoring efforts required to begin Phase B formulation activities in January 2018. The FY 2019 Request supports payload development activities leading up to the planned GUSTO Integrated Baseline Review and Critical Design Review.

THE IMAGING X-RAY POLARIMETRY EXPLORER (IXPE)

NASA selected the Imaging X-ray Polarimetry Explorer (IXPE) a small Explorer-class mission to continue into Phase B formulation in January 2017. IXPE will examine polarized x-ray emissions from both galactic and extragalactic x-ray sources such as neutron stars and black holes. This will allow the investigation of general relativistic and quantum effects in the extreme environment associated with these sources. IXPE will launch into a low Earth orbit at a low inclination for a two-year mission. IXPE entered Phase B formulation in October 2017, after completing a System Requirements Review.

THE X-RAY ASTRONOMY RECOVERY MISSION (XARM)

X-ray Astronomy Recovery Mission (XARM) is a joint NASA and JAXA mission that will recover the soft X-ray spectroscopic capability lost with the Hitomi mission that ended in March 2016. The key scientific objective of XARM is to pioneer a new horizon of the Universe with unprecedented high-resolution X-ray spectroscopy. XARM will provide breakthrough science in a number of areas, including structure and formation of the Universe, the evolution of clusters of galaxies, and the transport and circulation of energy in the cosmos. NASA is developing key components of the main instrument, the Resolve Soft X-ray Spectrometer, and will supply the X-ray mirror assemblies for the observatory. NASA's contribution to XARM entered Phase A formulation after completing its System Requirements Review in September 2017.

ASTROPHYSICS EXPLORERS FUTURE MISSIONS

Astrophysics Explorers Future Missions funding supports future astrophysics Explorers missions and MOs through concept studies and selections. During FY 2019, NASA will release an Announcement of Opportunity for Astrophysics Small Explorers and Missions of Opportunity. If the President’s Budget proposal for Astrophysics is enacted, including the termination of WFIRST and increase to the Astrophysics Explorer program, NASA will also issue an Announcement of Opportunity for a probe-class mission.

ASTROPHYSICS EXPLORERS PROGRAM MANAGEMENT

Astrophysics Explorers program management provides programmatic, technical and business management of ongoing missions in formulation and development.

OTHER MISSIONS AND DATA ANALYSIS

OPERATING MISSIONS

NEUTRON STAR INTERIOR COMPOSITION EXPLORER (NICER)

The NICER instrument launched on June 3, 2017 to the external logistics carrier of the ISS for an 18-month mission. Its main goal is spectroscopic X-ray observations of neutron stars with high time resolution, to measure their masses and radii precisely and thus test models for how matter behaves at such extreme densities. A neutron star squeezes more than 1.4 solar masses into a city-size volume, so the density and pressure are higher than in atomic nuclei. NICER also measures time-fluctuating X-rays from other sources, such as disks of hot gas pouring onto a black hole or neutron star from a stellar companion, or the gas around very massive black holes at the centers of galaxies.

Recent Achievements

NICER already made the most precise timing measurements of X-rays from the pulsar PSR J0030+0451, a neutron star that spins over 200 times per second. NICER has also observed X-ray flares from gas falling onto black holes from a companion star; scientists can use these data to measure how fast the black hole is spinning.

SWIFT

The Neil Gehrels Swift Observatory is a multi-wavelength space-based observatory that studies the position, brightness, and physical properties of gamma-ray bursts. Swift is a MIDEX class mission that launched in 2004 and is now in extended mission operations. It continues to provide data that allows scientists to solve the mystery of the origin of gamma-ray bursts and observe the birth cries of black holes. Swift is uniquely equipped to make rapid-response observations to fast-breaking events. Therefore, as well as revolutionizing gamma-ray burst science, Swift is a valuable facility for understanding the transient universe, ranging in distance from solar system studies to distant quasars, and in time from the present to the epoch of reionization. Scientists implemented the observations selected under Cycle 13 of the Guest Observer program, and NASA received proposals for Cycle 14 on February 22, 2017. The 2016 Senior Review of Operating Missions recommended continuing Swift operations through FY 2019. This budget supports that recommendation.

Recent Achievements

Swift has detected and characterized more than 1,300 gamma ray bursts to date. Swift's Ultraviolet/Optical Telescope imaged the kilonova produced by merging neutron stars in the galaxy NGC 4993 on August 18, 2017, about 15 hours after LIGO and Fermi detected gravitational waves and the gamma-ray burst. The Swift observations represent the first detection of a gravitational wave event in the ultraviolet. This brief bright UV pulse likely came from material blown away by the short-lived disk of debris that powered the gamma-ray burst; its rapid fading implies that the debris was expanding at nearly a tenth of light-speed. An international team of astronomers used Swift and made a major modification to a popular theory for the active centers of galaxies, which says that active centers of galaxies appear to fall into two distinct types solely because we view the galaxies from Earth at different angles. Recent Swift results suggest that the central black holes in these two types of galaxy are in fact different: they consume matter and spit out energy at very different rates.

OTHER MISSIONS AND DATA ANALYSIS

NUCLEAR SPECTROSCOPIC TELESCOPE ARRAY (NUSTAR)

Launched in June 2012, NuSTAR completed its prime mission in July 2014 and is now in extended mission operations. NuSTAR enables scientists to locate massive black holes in other galaxies, locate and examine the remnants of collapsed stars in our galaxy, observe selected gamma-ray sources, and observe any new supernovae in the local group of galaxies. NuSTAR's key science products are sensitive X-ray survey maps of the celestial sky. NuSTAR offers opportunities for a broad range of science investigations, ranging from probing cosmic ray origins and studying the extreme physics around collapsed stars to mapping micro flares on the surface of the Sun. NuSTAR performs follow-up observations to discoveries made by Chandra and Spitzer scientists. NuSTAR research teams collaborate with those using Fermi to make simultaneous observations. The NuSTAR mission implemented a Guest Observer Facility for U.S. observers in 2015 Scientists implemented the observations selected under Cycle 3 of the Guest Observer program, and NASA received proposals for Cycle 4 on January 19, 2017. The 2016 Senior Review of Operating Missions recommended continuing NuSTAR operations through FY 2019. This budget supports that recommendation.

Recent Achievements

NuSTAR continued its highly successful science program, providing invaluable new insights into the high-energy phenomena in the universe. A study using NuSTAR shows that in the late stages of galaxy mergers, huge amounts of gas and dust fall inward, hiding the extremely bright active galactic nucleus. The combined effect of the gravity of two merging galaxies slows down the gas and dust that would otherwise orbit around the center, so that it falls towards the central black hole. NuSTAR observations of 49 have revealed a tiny "dwarf" galaxy with a huge black hole, more than 2 percent of the galaxy's own mass, which is merging with a much larger galaxy. Astronomers had thought that actively feeding black holes would dominate the high-energy X-ray light in galaxies. However, NuSTAR has found two neutron stars, the dense remnants of dead stars, that are brighter than the black holes in the galaxy in the high-energy X-rays that NuSTAR is uniquely capable of measuring. NuSTAR observations of the brightest object in the Milky Way's close neighbor galaxy, Andromeda, shows that it is a pulsar, Swift J0042.6+4112, a highly magnetized and spinning neutron star. NuSTAR observations of a highly luminous source in the galaxy NGC 5907 showed that it too is a pulsar, spinning on its axis more than once a second while feeding on hot gas. The brightest known pulsar emits the same amount of energy in one second as our sun does in three-and-a-half years.

HELIOPHYSICS

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Heliophysics Research	180.8	--	**242.7**	234.3	226.7	217.9	220.6
Living with a Star	368.4	--	**247.8**	103.4	83.5	93.2	127.8
Solar Terrestrial Probes	38.8	--	**91.0**	89.9	177.7	175.6	247.9
Heliophysics Explorer Program	86.7	--	**109.2**	263.1	202.9	204.1	94.4
Total Budget	**674.7**	**--**	**690.7**	**690.7**	**690.7**	**690.7**	**690.7**

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Heliophysics

HELIOPHYSICS RESEARCH

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	FY 2020	Notional FY 2021	FY 2022	FY 2023
Heliophysics Research and Analysis	39.4	--	**71.2**	66.6	58.6	58.6	58.6
Sounding Rockets	53.3	--	**61.1**	63.1	68.1	60.1	65.1
Research Range	24.3	--	**29.6**	27.3	25.6	25.6	25.6
Other Missions and Data Analysis	63.8	--	**80.9**	77.2	74.4	73.5	71.3
Total Budget	**180.8**	**--**	**242.7**	**234.3**	**226.7**	**217.9**	**220.6**

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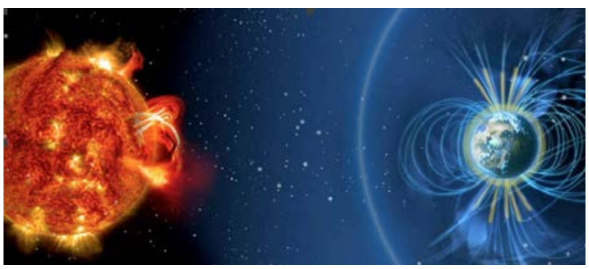

Heliophysics research studying space around Earth and our planets has applications far out into the universe, including supporting the search for life and habitable planets. Simulations of the radiation pouring out from the star Proxima Centauri show that an Earth-like rocky planet would not be able to hold onto its life-sustaining atmosphere in the same orbit as the recently found exoplanet Proxima b. In the absence of observing such exoplanets directly, using knowledge of our own star and planet is the best way to identify potentially habitable planets elsewhere.

The Sun, a typical small star midway through its life, governs the solar system. The Sun wields its influence through its gravity, radiation, solar wind, and magnetic fields, all of which interact with the Earth and its space environment to produce space weather, which can affect human technological infrastructure and activities. Heliophysics seeks to understand the Sun, heliosphere, and planetary environments as a single connected system. NASA seeks to answer these fundamental questions:

- How and why does the Sun vary?
- How do Earth and the heliosphere respond to the Sun's changes?
- How do the Sun and the solar system interact with the interstellar medium?
- How do these processes affect human activities?

Heliophysics Research improves our understanding of fundamental physical processes throughout the solar system, and enables us to understand how the Sun, as the major driver of the energy throughout the solar system, affects our technological society. The scope of Heliophysics ranges from the Sun's interior to Earth's upper atmosphere and beyond, through interplanetary space to the end of the region of the Sun's influence, far beyond the outer planets.

For more information, go to https://science.nasa.gov/heliophysics/programs/research.

HELIOPHYSICS RESEARCH

EXPLANATION OF MAJOR CHANGES IN FY 2019

The FY 2019 Request enables NASA to increase the funding for both Heliophysics Research and Analysis and Guest Investigators, as recommended in the Decadal Survey Diversify, Realize, Integrate, Venture, Educate (DRIVE) initiative. The Decadal Survey found the Principal Investigator grant program, comprising only 10 percent of the previous total Heliophysics budget, to be unsustainable for the community. The FY 2019 request increases the grant program to approximately 20 percent of the total budget, aligning it to Decadal Survey recommendations. The increase in funding for CubeSats is also in response to the DRIVE initiative. This increase enables the implementation of meaningful science-directed CubeSats (at a cost of ~$2-4 million), as compared to educational CubeSats (~$1 million). NASA plans at least two CubeSat launches in FY 2019, as well as additional selections and ongoing development of selected CubeSats.

ACHIEVEMENTS IN FY 2017

In FY 2017, NASA continued its restructured and improved portfolio of competed research programs by fully implementing the Diversify, Realize, Integrate, Venture, Educate (DRIVE) initiative, as outlined in the National Academies' 2013 Decadal Survey for Solar and Space Physics. The Heliophysics Division continued implementation of CubeSats on behalf of the Science Mission Directorate (SMD).

NASA continued a competed Heliophysics Research program with emphasis on synergy of data analysis with key enhancement from numerical simulations, theory, or modeling. It will continue to focus on the development of key technologies for use in future missions. The current technology development focuses on reducing sensor size, weight, and power. Future missions will benefit from an increase in sensor density as well as the new option of constellations and swarms of in-situ measurements in a sensor web matched to the temporal and spatial scales of energetic space plasma phenomena.

The sounding rocket mission manifest featured 18 missions in FY 2017. Five rockets successfully launched from the Poker Flat Research Range in Alaska between January and March 2017. Two technology demonstration missions from the WFF enabled water recovery of vacuum-sealed telescope payloads, as well as more reliable deployment and detonation of small vapor tracer ampules for the purpose of upper atmosphere wind measurements. The Program continued planning for a potential FY 2019 campaign in Australia, which will likely feature several missions investigating celestial targets of interest in the Southern sky.

WORK IN PROGRESS IN FY 2018

In FY 2018, the Heliophysics Research program anticipates science results from the analysis of data from 18 active space missions (27 individual spacecraft) that comprise the Heliophysics System Observatory. These include ACE, AIM, Geotail, Hinode, Interstellar Boundary Explorer (IBEX), Interface Region Imaging Spectrograph (IRIS), Magnetospheric Multiscale Satellites (MMS) (four spacecraft), Ramaty High Energy Solar Spectroscopic Imager (RHESSI), Solar Dynamics Observatory (SDO), Solar and Heliospheric Observatory (SOHO), Solar Terrestrial Relations Observatory (STEREO), Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED), Time History of Events and Macroscale Interactions during Substorms (THEMIS) (five spacecraft), Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS), Van Allen Probes (two spacecraft), Voyager (two spacecraft), and Wind. The Space Environment Testbeds (SET) project, a collection of technology experiments, should fly along with several other spacecraft in spring 2018. The anticipated awards of small research investigations will also continue to contribute to heliophysics science advancements.

The current sounding rockets mission manifest features 18 missions in FY 2018 in multiple remote locations. The Program will go to the Poker Flat Research Range in the winter for four missions, Norway in the spring for two missions, and to Kwajalein in the summer for two missions. Furthermore, the Program will execute the bulk of the preparations for an early FY 2019 campaign in Norway, called the Grand Challenge. This will involve fabrication, testing, and ground support set-up for six missions from two launch sites (Andoya and Svalbard).

The sounding rocket program will also launch the first in a series of rockets for the Jet Propulsion Laboratory to test the re-entry dynamics of supersonic parachutes for future Mars landings. Additionally, the final prototype Peregrine motor will undergo an instrumented disposal/test burn at WFF that will include an adapter section to measure insulation erosion. The NASA Engineering and Safety Center redesign effort continues with the Critical Design Review (CDR) in the spring of 2018.

In addition, Heliophysics plans three CubeSats launches in FY 2018. Compact Radiation Belt Explorer (CeREs) will study what energizes electrons and causes their escape from the radiation belts. Scintillation Observations and Response of The Ionosphere to Electrodynamics (SORTIE) will study space weather sources of wave-like plasma perturbations in the ionosphere. The Tandem Beacon-Explorer (TBEx) will study tropical weather relationship to ionospheric bubbles.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

In FY 2019, the Heliophysics Research program anticipates significant science results from the analysis of data from the Ionospheric Connections Explorer (ICON) mission, from the Global-scale Observations of the Limb and Disk (GOLD) mission of opportunity, and from SET, as well as results from 18 active space missions (27 individual spacecraft) that comprise the Heliophysics System Observatory. The anticipated awards of small research investigations will also continue to contribute to heliophysics science advancements.

The current sounding rockets mission manifest features 18 missions in FY 2019 in multiple remote locations. The Program will go to the Poker Flat Research Range in the winter for four missions, Norway in the spring for the Grand Challenge campaign, and to Australia, which will feature several missions investigating celestial targets of interest in the Southern sky.

NASA plans to launch at least two CubeSats in FY 2019. The Electron Losses and Fields Investigation (ELFIN) will study dominant wave-loss mechanism of relativistic electrons. SMD will continue to collaborate with the Human Exploration and Operations Mission Directorate (HEOMD) to enable the CubeSat mission to Understand Solar Particles (CUSP) on the first flight using the Space Launch System (SLS), Exploration Mission-1 (EM-1). The EM-1 CubeSat began implementation in FY 2015, preparing for possible launch in FY 2019.

Program Elements

RESEARCH RANGE

The Research Range Services (RRS) project provides operations support, maintenance, and engineering for the Wallops Launch Range and Instrumentation. The range and instrumentation support suborbital, orbital, and aircraft missions conducted on behalf of NASA and the Department of Defense at the WFF and at remote sites around the world. New work includes support for NASA technology missions, unmanned aerial vehicle flights, and commercial launch and flight projects.

The range instrumentation includes meteorological, telemetry, radar, command, launch and range control centers, and optical systems. RRS mobile assets provide range services at other ranges and remote locations around the world.

SOUNDING ROCKETS

The Sounding Rockets Project supports the NASA strategic vision and goals for Earth Science, Heliophysics, Planetary Science, and Astrophysics. The missions flown annually by the project provide researchers with unparalleled opportunities to build, test, and fly new instrument and sensor design concepts while simultaneously conducting world-class scientific research. Coupled with a hands-on approach to instrument design, integration, and flight, the short mission life cycle helps ensure that the next generation of space scientists receives the training and experience necessary to move on to NASA’s larger, more complex space science missions.

With the capability to fly higher than many low Earth orbiting satellites and the ability to launch on demand, sounding rockets often offer the only means to study specific scientific phenomena of interest to many researchers. Unlike instruments on board most orbital spacecraft or in ground-based observatories, sounding rockets can place instruments directly into regions where and when the science is occurring to enable direct, in-situ measurements. The mobile nature of the project enables researchers to conduct missions from strategic vantage points worldwide. Telescopes and spectrometers to study solar and astrophysics phenomena fly on sounding rockets to collect unique science data and test prototype instruments for future satellite missions.

HELIOPHYSICS RESEARCH AND ANALYSIS

This project supports basic research, solicited through NASA’s annual Research Opportunities in Earth and Space Science (ROSES) announcements. These research activities address our understanding of the Sun and planetary space environments, including the origin, evolution, and interactions of space plasmas and electromagnetic fields throughout the heliosphere and in connection with the galaxy. Understanding the origin and nature of solar activity and its interaction with the space environment of the Earth is a particular focus. This project supports Heliophysics Grand Challenge Research (theory) (GCR), Low Cost Access to Space (LCAS) investigations, instrument development, and necessary research directly linked to Heliophysics science questions.

Heliophysics GCR investigations are the foundation of the Heliophysics Research and Analysis project. They lead the way to new understanding of previous investigations and drive science concepts for future missions. The Heliophysics GCR element supports large Principal Investigator (PI)-proposed team efforts that require a critical mass of expertise to make significant progress in understanding complex physical processes with broad importance.

LCAS investigations use spaceflight of experimental instrumentation to achieve scientific goals and proof-test new technology that may ultimately find application in larger or strategic Heliophysics space missions. These investigations may use a range of flight opportunities, including suborbital rockets, suborbital reusable launch vehicles, ISS payloads, CubeSats, and balloon flights.

Instrument development investigations develop technology with promise for use in scientific investigations on future Heliophysics science missions. These investigations may include the development of laboratory instrument prototypes, but not of flight hardware. The goal is to define and develop scientific instruments and/or components of such instruments to the point where complete instruments are ready for future Announcements of Opportunity (AOs) or Missions of Opportunity (MO) without significant additional technology development.

Supporting research investigations guide the direction and content of future science missions. They employ a variety of fundamental research techniques (e.g., theory, numerical simulation, and modeling), analysis, and interpretation of space data, development of new measurement concepts, and laboratory measurements of relevant atomic, plasma and nuclear parameters. They are essential in fully exploiting Heliophysics mission research data collected between the outer edge of the Earth's atmosphere and the interaction of the Sun and solar wind with the local galactic environment currently explored by Voyager.

Program Schedule

NASA implements the Heliophysics Research program via a competitively selected process. NASA releases research solicitations each year through the Research Opportunities in Earth and Space Science (ROSES) NASA Research Announcements (NRA), aiming to initiate research for about one-third of the program, given the selected investigations are typically three-year awards. Therefore, NASA will allocate FY 2019 funds to ROSES-2018, ROSES-2017, and ROSES-2016 selections.

HELIOPHYSICS RESEARCH

Date	Significant Event
Q1, Q2 FY 2018	ROSES-2017 selections: Oct 2017–May 2018
Q2 FY 2018	ROSES-2018 solicitation: Feb 2018
Q3/Q4 FY 2018	Review of proposals submitted to Heliophysics ROSES-2018 elements
Q1 FY 2019	ROSES-2018 selection within six to nine months of receipt of proposals
Q2 FY 2019	ROSES-2019 solicitation
Q1 FY 2020	ROSES-2019 selection within six to nine months of receipt of proposals

Program Management & Commitments

Program Element	**Provider**
Research and Analysis	Provider: Headquarters (HQ) Lead Center: HQ Performing Centers: Goddard Space Flight Center (GSFC), Marshall Space Flight Center (MSFC), Jet Propulsion Laboratory (JPL), Langley Research Center (LaRC), Johnson Space Center (JSC) Cost Share Partners: None
Sounding Rockets and Research Range	Provider: GSFC Lead Center: HQ Performing Center: GSFC Cost Share Partners: None
Heliophysics Operating Missions	Provider: GSFC, JPL, MSFC Lead Center: HQ Performing Center: GSFC, JPL, MSFC Cost Share Partners: None

Acquisition Strategy

NASA issues solicitations for competed research awards each February in the ROSES NRAs. To the widest extent possible, NASA fully and openly competes all new acquisitions. Proposals are peer-reviewed and selected from the annual ROSES announcement. Universities, government research laboratories, and industry partners throughout the United States participate in research projects. NASA previously selected the Heliophysics operating missions and instrument teams via NASA AOs. NASA evaluates the allocation of funding among the operating missions through the Heliophysics Senior Review process.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Sounding Rocket Operations	Orbital ATK, Dulles, VA	Various

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Mission Senior Review Panel	Oct 2017	A comparative evaluation of Heliophysics operating missions	The report, released in Nov 2017, assessed missions individually, and as part of a system observatory	Apr 2020
Relevance	NASA Advisory Council Heliophysics Advisory Committee	2017	To review progress towards Heliophysics objectives in the NASA Strategic Plan	All areas were rated green as documented in the FY 2017 Agency Financial Report	Future reviews will be conducted by newly chartered Heliophysics Advisory Committee
Relevance	Heliophysics Advisory Committee	2017	To review progress towards Heliophysics objectives in the NASA Strategic Plan	The HAC briefed the Heliophysics acting Division Director.	2018

OTHER MISSIONS AND DATA ANALYSIS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Science Planning and Research Support	6.7	--	**6.7**	6.7	6.7	6.7	6.7
Directed Research & Technology	0.0	--	**0.0**	0.0	3.9	4.2	4.2
CubeSat	15.0	--	**22.0**	18.5	10.0	10.0	10.0
Solar Data Center	1.1	--	**1.3**	1.1	1.2	1.2	1.2
Data & Modeling Services	2.8	--	**3.0**	3.0	3.0	3.0	3.0
Space Physics Data Archive	2.3	--	**2.3**	2.3	2.3	2.3	2.3
Guest Investigator Program	11.6	--	**21.5**	21.5	21.5	21.5	21.5
Community Coordinated Modeling Center	2.3	--	**2.3**	2.4	2.4	2.4	2.4
Space Science Mission Ops Services	11.5	--	**11.5**	11.6	13.1	11.9	10.7
Voyager	5.6	--	**5.6**	5.5	5.5	5.5	4.9
SOHO	2.3	--	**2.3**	2.3	2.3	2.4	2.2
Wind	2.2	--	**2.2**	2.2	2.2	2.2	2.0
Geotail	0.4	--	**0.2**	0.2	0.2	0.2	0.2
Total Budget	**63.8**	**--**	**80.9**	**77.2**	**74.4**	**73.5**	**71.3**

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The Voyager team tested a set of four backup thrusters, dormant since 1980– and discovered they still worked perfectly. They are located on the back side of the spacecraft in this orientation. "With these thrusters that are still functional after 37 years without use, we will be able to extend the life of the Voyager 1 spacecraft by two to three years," said Suzanne Dodd, project manager for Voyager at NASA's Jet Propulsion Laboratory, Pasadena, California.

NASA accumulates, archives, and distributes data collected by the Heliophysics System Observatory, a fleet of operating spacecraft. Combining the measurements from all of these observing platforms enables interdisciplinary, connected systems science across the vast spatial scales of our solar system. This collective asset enables the data, expertise, and research results to contribute directly to fundamental research on solar and space plasma physics and to the national goal of real-time space weather prediction. NASA teams support day-to-day mission operations for NASA spacecraft and data analysis to advance the state of space science and space weather modeling. NASA conducts science community-based projects to evaluate research models containing space weather information that is of value to industry and government agencies. Heliophysics data centers archive and distribute the science data from operating missions in the Living With a Star (LWS), Solar Terrestrial Probes (STP), Research, and Explorer programs.

Mission Planning and Other Projects

SCIENCE PLANNING AND RESEARCH SUPPORT

This project supports NASA's participation in proposal reviews by peer review panels, decadal surveys, and National Academies' studies.

DIRECTED RESEARCH AND TECHNOLOGY

This project funds the civil service staff that work on emerging flight projects, instruments, and research.

CUBESAT

Heliophysics implemented a CubeSat project in response to the 2013 Decadal Survey DRIVE initiative recommendation. The aim of the project is to explore the viability of this lower-cost option for enabling scientific discovery.

CubeSats are small spacecraft, built to a standardized form-factor of size and mass, which can launch as secondary or ride-share payloads. With development costs between $1 million and $6 million per investigation and with rapid development cycles, CubeSats can provide frequent science and technology flight opportunities.

This approach is similar to the traditional NASA suborbital programs that use sounding rockets, balloons, and aircraft, but extends the range of opportunities. CubeSats have significant potential to leverage exploratory and systematic science observations at minimal additional cost.

The CubeSat project initially encompassed all Science Mission Directorate (SMD) themes and disciplines. From 2014 to 2018, the CubeSat project initiated 21 investigations in an exploration of management and implementation required for a new kind of flight program. Beginning in 2018, SMD science divisions will conduct CubeSat investigations independently, using the lessons learned from the cross-discipline project.

The CubeSat project will complete the cross-discipline investigations already started and will initiate new Heliophysics investigations in the $1 million to $3 million range beginning in 2019. In addition, based on the capabilities demonstrated in the pathfinder stage, the Heliophysics CubeSat project will expand to take advantage of new science achievable via investigations in the $4 million to $7 million range. The larger investigations will enable the development of remote sensing investigations with more sophisticated CubeSats as well as small constellations of in-situ CubeSat investigations.

OTHER MISSIONS AND DATA ANALYSIS

SOLAR DATA CENTER

The Solar Data Center provides mission and instrument expertise to enable high-quality analysis of solar physics mission data. It provides leadership for community-based, distributed development efforts to facilitate identifying and accessing solar physics data, including ground-based coordinated observations residing in the Virtual Solar Observatory. The center also provides a repository for software used to analyze these data. The Virtual Solar Observatory is a software system that links together distributed archives of solar data into a unified whole, along with data search and analysis tools.

DATA AND MODELING SERVICES

This project supports missions in extended operations and missions transitioning to decommissioning to prepare their data holdings for long-term archival curation. This project also provides for the creation of higher-level data products, which are of significant use to the science community and not funded during the prime mission. Higher-level data products are data that combine results of multiple missions and/or instruments. Elements of this project are competed through the annual ROSES competitive announcement.

SPACE PHYSICS DATA ARCHIVE

The Space Physics Data Facility (SPDF) ensures long-term data preservation and online access to non-solar heliophysics science data. It operates key infrastructure components for the Heliophysics Data Environment, including inventory and web service interfaces to systems and data. It also provides unique enabling science data services.

GUEST INVESTIGATOR PROGRAM

The Guest Investigator program maximizes the return from currently operating Heliophysics missions by supporting studies consistent with the science goals of these missions and those expressed in the 2013 decadal survey and 2014 SMD Science Plan. These competitive research investigations use data from multiple spacecraft, as appropriate. Investigations addressing global system science are strongly encouraged, as Heliophysics is, by its nature, the investigation of a large-scale, complex, connected system.

COMMUNITY COORDINATED MODELING CENTER (CCMC)

The Community Coordinated Modeling Center (CCMC) is a multi-agency partnership to enable and perform the research and development for next-generation heliophysics and space weather models. The center provides the United States and international research community access to simulations to enable “runs on demand,” using models to study space weather events in near-real time. This allows the comparison of observational data and model parameters during or shortly after solar activity, thereby improving accuracy of the models.

OTHER MISSIONS AND DATA ANALYSIS

SPACE SCIENCE MISSION OPERATIONS SERVICES

Space Science Mission Operations Services manages the on-orbit operations of GSFC Space Science missions. Services include consistent processes and infrastructure for missions operated at GSFC, Johns Hopkins University Applied Physics Laboratory (JHU-APL), Orbital-Alliant Techsystems (Orbital-ATK), Pennsylvania State University, and University of California at Berkeley. Space Science Mission Operations Services also sustains an operational infrastructure for current and future missions.

Operating Missions

VOYAGER

The Voyager Interstellar Mission is exploring the interaction of the heliosphere and the local interstellar medium. Voyager 1 is making the first in-situ observations of the region outside the heliosphere from about 138 astronomical units (AU), or 138 times Earth's distance from the Sun, and is traveling at a speed of 3.6 AU per year. Voyager 2 is about 114 AU from the Sun and traveling at a speed of about 3.3 AU per year. Spacecraft power should be adequate for currently operating instruments through 2020.

Recent Achievements

Analysis of data from NASA Heliophysics Voyager, IBEX and Cassini missions proposes a new theory on the shape of the heliosphere. The data suggest that the heliosphere is spherical rather than comet-shaped as previously thought. A new analysis data, spanning a full 11-year solar cycle, supports the assertion that the heliosphere has no tail, and resembles more of a sphere. A rounded heliosphere could be the result of a number of factors. Data from Voyager 1 -- which is currently past the heliopause -- show that the interstellar magnetic field (IMF) beyond the heliosphere is stronger than scientists previously thought. This means that the IMF could interact with the solar wind at the edges of the heliosphere and compact what scientists thought was the heliosphere's tail, creating a spherical shape. Measurements taken from Voyager show that it takes nearly one year for changes in solar activity carried in the solar wind, to propagate out to the nose of the heliosphere. Understanding the shape of the heliosphere gives us crucial information about the space that surrounds us, known as the local interstellar medium.

SOLAR AND HELIOSPHERIC OBSERVATORY (SOHO)

SOHO reached a milestone on December 2, 2017, when the spacecraft turned 22 years old. SOHO, a joint mission of the European Space Agency (ESA) and NASA, has been a dependable solar watchdog, providing the only Earth-Sun line coronagraph images of solar storms. Citizen scientists have used SOHO to discover more than 3,000 comets, a capability no one anticipated before launch. CMEs drive most of the space weather effects in the inner heliosphere. SOHO continues to provide essential early alert space weather observations used as inputs to models that further our understanding of the Sun's effect on the Earth.

Recent Achievements

The first detection of gravity-wave modes on the Sun in SOHO data revealed that the solar core is rotating four times faster than the solar surface. This is the first (albeit) indirect measure of the rotation speed of the Sun's core. It raises a new set of questions about, for example, how differently rotating layers of the

OTHER MISSIONS AND DATA ANALYSIS

Sun interact, and what the rotation of the core tells us about its composition. Scientists consider this one of SOHO's all-time top discoveries, which is opening a new area of solar research.

WIND

The Wind spacecraft studies the solar wind and its impact on the near-Earth environment. It addresses wave-particle interaction processes in the space environment, evolution of solar activity in the heliosphere, and geomagnetic impact of solar activity. Wind performs in-situ studies using unique capabilities, such as three-dimensional particle distributions over a wide range of energies, and delivers higher time resolution than available from any other mission. Wind provides critical measurements of the solar wind and space weather events. Correlating those with measurements from the upcoming Parker Solar Probe and Solar Orbiter Collaboration (SOC) missions will improve our understanding of these events as they move out from the Sun. These multi-spacecraft measurements constrain models of space weather events and improve their predictive capabilities.

Recent Achievements

One of the major goals of instruments on the Wind spacecraft is to extend the measurements of elemental abundances in Solar Energetic Particle (SEP) events to include atoms throughout the periodic table. The extremely high temperatures in the solar wind tend to remove electrons from all elements leaving atoms with a net positive charge showing the elements as ions. Small impulsive events on the Sun produce a set of Wind observations revealing a strong variation in the abundance of elements ranging from He (Helium) to Pb (Lead). The variation shows a dependence on the ratio of the ion mass to ion charge. Variations in the temperature of these source regions can explain the variation of elements. This helps to explain many of the subtle event-to-event variations that suggest shocks at the Sun are averaging over many small impulsive events. With these new 2017 results, Wind is helping us understand the physics of the energetic particle enhancements originally observed over 30 years ago.

GEOTAIL

Geotail enables scientists to assess data on the interaction of the solar wind and magnetosphere.
July 24, 2015 marked the 23rd anniversary of the launch of Geotail. Its instruments continue to function, sending back crucial information about how auroras form, how energy from the Sun funnels through near-Earth space, and the ways in which magnetic field lines move and rebound, creating explosive bursts that rearrange the very shape of our magnetic environment. The Geotail mission is a collaborative project undertaken by the Japanese Institute of Space and Astronautical Science and NASA.

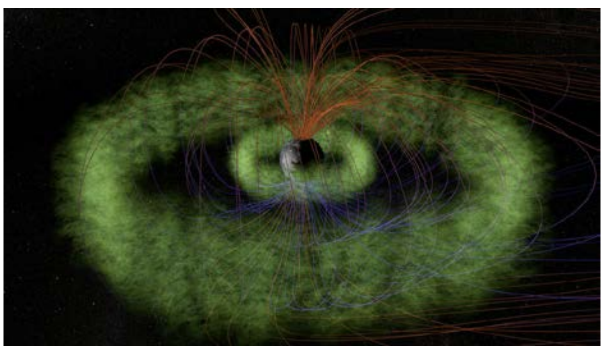
LIVING WITH A STAR

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Parker Solar Probe	232.5	241.6	**107.2**	30.6	22.1	22.2	21.2
Solar Orbiter Collaboration	79.9	59.2	**62.3**	4.1	4.2	4.2	4.3
Other Missions and Data Analysis	56.0	--	**78.2**	68.7	57.2	66.7	102.3
Total Budget	**368.4**	**--**	**247.8**	**103.4**	**83.5**	**93.2**	**127.8**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



The Van Allen Belts, shown in green in this illustration, are concentric doughnut-shaped belts filled with charged particles, trapped by Earth's magnetic field. Determining how these particles escape and affect near-Earth space requires having observatories in multiple locations – not unlike having terrestrial weather sensors around the globe. Late on January 20, 2016, the Van Allen Probes observed chorus waves within the belts and immediately after, the FIREBIRD II CubeSat saw microbursts of particles scattering out of the belts. The new results confirm that the chorus waves play an important role in controlling the outflow of energetic electrons — one extra piece of the puzzle to understand how high-energy electrons are hurled so violently from the radiation belts. This information can additionally help further improve space weather predictions.

The Living With A Star (LWS) program targets specific aspects of the Sun-Earth system that affect life and society. LWS provides a predictive understanding of the Sun-Earth system, linkages among the interconnected systems, and, specifically, space weather conditions at Earth and the interplanetary medium. Measurements and research from LWS missions may contribute to advances in operational space weather forecasting that help prevent damage to spacecraft, communications and navigation systems, and power grids. LWS products improve our understanding of ionizing radiation, which has human health implications on the ISS and high-altitude aircraft flight, as well as operations of future space exploration with and without human presence. LWS products improve the characterization of solar radiation for global climate change, surface warming, and ozone depletion and recovery.

For more information, go to http://science.nasa.gov/about-us/smd-programs/living-with-a-star/.

LIVING WITH A STAR

EXPLANATION OF MAJOR CHANGES IN FY 2019

An increase to LWS Science focuses on space weather research, enhancing the ability to forecast and characterize space weather events in collaboration with NASA's inter-agency partners. This investment would provide targeted research opportunities for research-to-operations and operations-to-research activities, as well as the necessary infrastructure (i.e., computational capacity, funding for high performance computing) and workforce needed to support research-to-operations efforts between NASA, the National Science Foundation and the National Oceanic and Atmospheric Administration.

PARKER SOLAR PROBE

Formulation	Development	Operations

FY 2019 Budget

		Actual	CR	Request		Notional				
Budget Authority (in $ millions)	**Prior**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**	**FY 2023**	**BTC**	**Total**
Formulation	247.1	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	247.1
Development/Implementation	545.2	232.5	241.6	**31.0**	0.0	0.0	0.0	0.0	0.0	1050.3
Operations/Close-out	0.0	0.0	0.0	**76.2**	30.6	22.1	22.2	21.2	78.5	250.8
2018 MPAR LCC Estimate	**792.3**	**232.5**	**241.6**	**107.2**	**30.6**	**22.1**	**22.2**	**21.2**	**78.5**	**1548.2**
Total Budget	**817.3**	**232.5**	**241.6**	**107.2**	**30.6**	**22.1**	**22.2**	**21.2**	**78.5**	**1573.2**
Change from FY 2018				**-134.4**						
Percentage change from FY 2018				**-55.6%**						

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

PROJECT PURPOSE

Eugene Parker, professor emeritus at the University of Chicago, visiting the spacecraft that bears his name, NASA's Parker Solar Probe, on October 3, 2017. Engineers in the clean room at the Johns Hopkins University Applied Physics Laboratory (JHU/APL) in Laurel, Maryland, where the probe was designed and is being built point out the instruments that will collect data as the mission travels directly through the Sun's atmosphere.

Parker Solar Probe (PSP) will explore the Sun's outer atmosphere, or corona, as it extends out into space. Parker will orbit at a distance from the Sun of less than five times the Sun's diameter, closer than any other spacecraft. Parker will repeatedly obtain direct in-situ coronal magnetic field, plasma, and white-light remote sensing observations in the region that heats the solar atmosphere and accelerates the solar wind. Parker's findings could revolutionize our knowledge and understanding of coronal heating and of the origin and evolution of the solar wind, answering critical questions posed in the 2003 and 2013 Heliophysics Decadal Surveys.

Its seven-year prime mission lifetime will permit observations over a significant portion of a solar cycle. Parker will enable direct sampling of plasma, providing observations that until now have been impossible. These observations will allow heliophysicists to verify and discriminate

PARKER SOLAR PROBE

Formulation	Development	Operations

between a broad range of theory and models that describe the Sun's coronal magnetic field and the heating and acceleration of the solar wind. Parker will enable NASA to gain a better understanding of the radiation environment in which future space explorers will work and live.

For more information, go to https://science.nasa.gov/missions/solar-probe.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

PROJECT PARAMETERS

After launch, expected in August 2018, Parker will orbit the Sun 24 times, gradually "walking in" toward the Sun with each pass. Parker's first close approach to the Sun occurs just three months after launch. Over a period of about seven years, seven Venus flybys will gradually reduce the spacecraft's orbit around the Sun. The closest points of each orbit come well within the path of Mercury, the closest planet to the Sun. On the final three orbits, Parker will fly within 3.8 million miles of the Sun's surface. That is about seven times closer than the Helios spacecraft, the current record holder for the closest solar pass.

ACHIEVEMENTS IN FY 2017

FY 2017 saw the completion of spacecraft systems and instruments, and integration and test of the spacecraft. Instruments and systems completed their assembly and test, and then each conducted a Pre-Environmental Review to approve going forward to final environmental testing. Upon successful completion of the environmental testing JHU/APL received the instruments or systems, where they underwent inspection and test prior to installation on the spacecraft. Throughout the year, JHU/APL conducted tests at various levels of the system, including electromagnetic interference and compatibility, magnetic characterization measurements, system functionality, fault management, mass and balance, and alignment of the Thermal Protection System sun shield. The Parker Project ended FY 2017 with a successful Mission-Level Pre-Environmental Review, allowing the Project to proceed to spacecraft-level environmental testing.

In May 2017, NASA officially renamed the mission (previously Solar Probe Plus) to 'Parker Solar Probe', after Dr. Eugene Parker, a world-renowned solar physicist and astrophysicist who, in the late 1950's while at the University of Chicago, predicted the solar wind. Some of the consequences of Dr. Parker's work include the beginning of an understanding of the fundamental principles underlying space weather, now recognized as one of the important factors that can cause severe damage to the economy and endanger the safety of citizens worldwide. Based on Dr. Parker's predictions, numerous researchers design their space missions to specifically validate and expand on his work. Dr. Parker also received NASA's Distinguished Public Service Award, NASA's highest recognition.

PARKER SOLAR PROBE

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2018

In FY 2018, the project began spacecraft-level environmental testing. Parker successfully completed Vibration testing in October 2017. Acoustic testing and separation shock testing is planned for November 2017, and the final test phase, Thermal Vacuum, is planned for December 2017 - January 2017. NASA plans to ship Parker to Cape Canaveral in early March 2018 for final integration and mating the launch vehicle. The Operational Readiness Review is planned for mid-May and the Key Decision Point-E (KDP-E) will take place in late June, approving the mission to proceed to the Operations and Sustainment phase. The launch window is July 31 - August 23 (24 days). The first Venus flyby will occur on September 28, 2018.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

In early FY 2019, the Parker mission will enter into Phase E, beginning its first science collection period in late October, and making its first close approach to the Sun on November 1, 2018. Within the year, the mission will make its second close approach/science collection phase and will return science data from both collection periods.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2019 PB Request
KDP-C	Mar 2014	Mar 2014
CDR	Mar 2015	Mar 2015
System Integration Review (SIR)	Jun 2016	May 2016
Launch	Aug 2018	Aug 2018
Start of Phase E	Oct 2018	Oct 2018
End of Prime Mission	Sep 2025	Sep 2025

PARKER SOLAR PROBE

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Development Cost Estimate ($M)	JCL (%)	Current Year	Current Year Development Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2015	1,055.7	70	2018	1,050.3	-0.5	LRD	Aug 2018	Aug 2018	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

NASA confirmed Solar Probe Plus to proceed into implementation phase in March 2014.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**1,055.7**	**1,050.3**	**-5.4**
Aircraft/Spacecraft	170.8	243.9	73.1
Payloads	143.4	164.2	20.8
Systems I&T	31.2	30.7	-0.5
Launch Vehicle	430.5	408.0	-22.5
Ground Systems	17.8	20.2	2.4
Science/Technology	4.5	4.5	0
Other Direct Project Costs	257.5	178.8	-78.7

PARKER SOLAR PROBE

Formulation	Development	Operations

Project Management & Commitments

GSFC provides program management. JHU-APL manages the project.

Element	Description	Provider Details	Change from Baseline
Expendable Launch Vehicle	Deliver the spacecraft to operational orbit.	Provider: United Launch Alliance (ULA) Lead Center: KSC Participating Centers: KSC Cost Share Partners: N/A	N/A
Ground Systems	Receive science and telemetry data from spacecraft, command spacecraft, and distribute science data to investigator teams.	Provider: JHU-APL Lead Center: GSFC Participating Centers: N/A Cost Share Partners: N/A	N/A
Spacecraft	Transport instruments to science destination, operate instruments, and modify orbit, including several Venus gravity assists.	Provider: JHU-APL Lead Center: GSFC Participating Centers: N/A Cost Share Partners: N/A	N/A
Instruments	Provide in-situ measurements and remote observations of the Sun.	Provider: NASA funded investigators Lead Center: GSFC Participating Centers: N/A Cost Share Partners: N/A	N/A

Project Risks

Risk Statement	Mitigation
If: The spacecraft is unable to resolve faults with sufficient speed, Then: Over-exposure of critical components to the solar environment may occur, leading to a mission-ending failure.	The project will develop a system response for every manageable fault and perform extensive ground testing and simulation of system fault responses. Management will consider the risk mitigated after these activities are complete.
If: The optical properties of the solar array result in a solar array that is colder than expected, Then: The cooling system margin above freezing may fall below acceptable levels, threatening the arrays.	The project will measure the optical properties of the solar array cover glass and perform the power-thermal analysis to assess margin during thermal vacuum testing in FY 2017. Management will consider the risk mitigated after these activities are complete.

PARKER SOLAR PROBE

Formulation	Development	Operations

Acquisition Strategy

PIs selected through the competitive AO are building the science instruments. JHU-APL builds the spacecraft, and competitively procures the spacecraft subassemblies, components, and parts. The project is refining the ground system components and requirements. GSFC manages the operations contracts.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Prime Contract and Mission Management	JHU-APL	Laurel, MD
FIELDS Experiment (FIELDS) magnetometers and plasma wave instrument	University of California, Berkeley	Berkeley, CA
Integrated Science Investigation of the Sun (ISIS) energetic particle instruments	Southwest Research Institute (SwRI)	San Antonio, TX
Solar Wind Electrons Alphas and Protons (SWEAP) plasma instruments	Smithsonian Astrophysical Observatory	Cambridge, MA
Wide-Field Imager for Solar Probe Plus (WISPR) heliospheric imager	Naval Research Laboratory	Washington, DC
Heliophysics Origins Investigation	JPL	Pasadena, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Jan 2014	Preliminary Design Review (PDR) to assess readiness for KDP-C	Successful, project ready to proceed to development	Mar 2015
Performance	SRB	Mar 2015	CDR to assess readiness for KDP-D	Successful, project's mission design is appropriately mature to continue with the final design and fabrication phase.	May 2016

PARKER SOLAR PROBE

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	May 2016	SIR to assess readiness for project to begin system I&T	Successful, project ready to proceed to integration and test	May 2018
Performance	SRB	May 2018	Operations Readiness Review (ORR) to assess readiness for project to operate the flight system	TBD	N/A

SOLAR ORBITER COLLABORATION

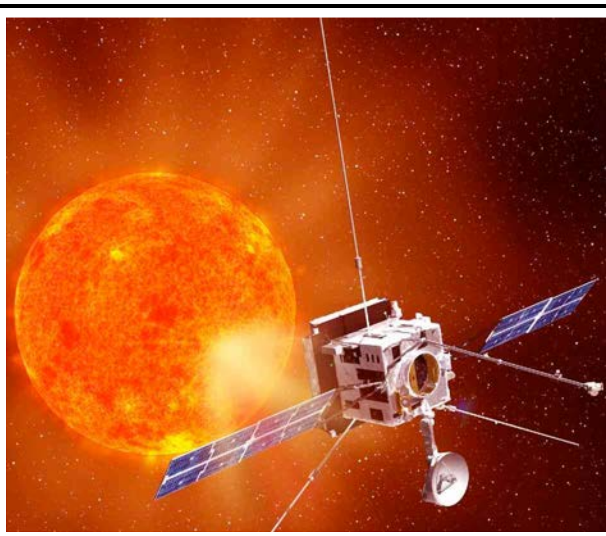
Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023	BTC	Total
Formulation	41.5	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	41.5
Development/Implementation	110.8	79.9	59.2	**60.1**	0.0	0.0	0.0	0.0	0.0	310.0
Operations/Close-out	0.0	0.0	0.0	**2.2**	4.1	4.2	4.2	4.3	16.1	35.2
2018 MPAR LCC Estimate	**152.2**	**79.9**	**59.2**	**62.3**	**4.1**	**4.2**	**4.2**	**4.3**	**16.1**	**386.6**
Total Budget	**152.2**	**79.9**	**59.2**	**62.3**	**4.1**	**4.2**	**4.2**	**4.3**	**16.1**	**386.6**
Change from FY 2018				**3.1**						
Percentage change from FY 2018				**5.2%**						

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



This ESA-led mission will improve the understanding of how the Sun determines the environment of the inner solar system and how fundamental plasma physical processes operate near the Sun.

PROJECT PURPOSE

The NASA and European Space Agency Solar Orbiter Collaboration mission will provide measurements that will give NASA better insight on the evolution of sunspots, active regions, coronal holes, and other solar features and phenomena. The instruments will explore the near-Sun environment to improve our understanding of the origins of the solar wind streams and the heliospheric magnetic field; the sources, acceleration mechanisms, and transport processes of solar energetic particles; and the evolution of CMEs in the inner heliosphere. To achieve these objectives, SOC will make in-situ measurements of the solar wind plasma, fields, waves, and energetic particles. SOC will also make imaging/spectroscopic observations. SOC will provide close-up views of the Sun’s polar-regions and far side. SOC will adjust its orbit to the direction of the Sun’s rotation to allow the spacecraft to observe one specific area for much longer than is currently possible.

SOLAR ORBITER COLLABORATION

Formulation	Development	Operations

ESA provides the spacecraft and operations, the ESA member states provide the majority of the instruments, and NASA provides the launch vehicle and two science investigations/instruments: the Solar Orbiter Heliospheric Imager (SoloHI) and the Heavy Ion Sensor (HIS). In return for its contributions, NASA will have access to the entire science mission data set.

For more information, go to https://science.nasa.gov/missions/solar-orbiter.

EXPLANATION OF MAJOR CHANGES IN FY 2019

Integration issues with the spacecraft recently led ESA to request a delay in the Solar Orbiter Launch Readiness Date from October 2018 to February 2019. It is now apparent that the February 2019 launch date is also not achievable. Solar Orbiter is an interplanetary mission and its next known "planetary launch window" is in February 2020. As NASA is providing the launch vehicle, the Launch Services Program is moving to reserve February 2020 on the Cape Canaveral launch range manifest, and the project is now planning for a February 2020 launch.

PROJECT PARAMETERS

A NASA-provided launch vehicle will place the ESA-provided SOC spacecraft into an inner heliospheric orbit around the Sun, with its closest approach ranging from 0.23 to 0.38 AU and the farthest distance from 0.73 to 0.88 AU. In the first phase of mission operations, SOC will orbit around the Sun's equator at about the same rate as the Sun's rotation. In the second phase, it will perform a Venus gravity assist maneuver between each rotation around the Sun. Each gravity assist maneuver will increase the SOC's inclination with respect to the Sun's equator so that the inclination will reach 27.5 degrees by the end of prime mission operations. This will enable the instruments to image the polar regions of the Sun clearly for the first time and make key measurements that will advance our understanding of the solar dynamo and the polarity reversal of the global magnetic field. The inclination will increase to 34 degrees by the end of a possible three-year extended mission, allowing better insight into the polar-regions.

ACHIEVEMENTS IN FY 2017

Naval Research Laboratory (NRL) completed the pre-environmental review, environmental testing, instrument calibration, pre-ship review, and delivery of the SoloHI flight instrument to the spacecraft integrator Airbus. Airbus mechanically and electrically integrated SoloHi to the spacecraft.

Southwest Research Institute (SwRI) completed the pre-environmental review, environmental testing, instrument calibration, pre-ship review, and delivery of the HIS flight instrument to Mullard Space Systems laboratory (MSSL). MSSL electrically tested and integrated the HIS instrument with the rest of the Solar Wind Analyzer suite.

SOC completed the Key Decision Point (KDP) Phase D. It captured all of the changes associated with the then planned Launch slip to February 2019.

SOLAR ORBITER COLLABORATION

Formulation	Development	Operations

The United Launch Alliance team successfully completed the Mission Specific Requirements Review, Coupled Loads Analysis of Solar Orbiter, Mission Integration Working Group, Ground Operations Working Group and an updated version of the Launch Vehicle Interface Control Document.

WORK IN PROGRESS IN FY 2018

At Airbus, instrument teams will continue to support instrument integration, alignment, and functional testing in preparation for environmental testing. After environmental testing is complete, the spacecraft and instruments will ship to Kennedy Space Center to begin pre-launch processing.

The United Launch Alliance team will complete the Critical Design Review (CDR), final Coupled Loads Analysis, trajectory analysis, of Solar Orbiter, hold the last Mission Integration Working Group, Ground Operations Working Group and finalize the Launch Vehicle Interface Control Document.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

NASA, ESA, and the instrument teams will continue preparations for the anticipated February 2020 launch and the subsequent start of data collection.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2019 PB Request
KDP-C	Mar 2013	Mar 2013
SoloHI Instrument CDR	Jun 2013	Oct 2013
HIS Instrument CDR	Feb 2014	Mar 2014
Pre-ship review	Jan 2015	Mar 2017
Launch	Oct 2018	TBD
Begin Phase E	Oct 2018	TBD
End of Prime Mission	Nov 2026	TBD

SOLAR ORBITER COLLABORATION

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2014	376.9	N/A	2018	310.0	-17.8	LRD	Oct 2018	Feb 2019	TBD

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

NASA confirmed SOC to proceed into implementation phase in March 2013.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**376.9**	**310.0**	**-66.9**
Aircraft/Spacecraft	0.0	0.0	0.0
Payloads	23.7	70.2	46.5
Systems I&T	0.0	0.0	0.0
Launch Vehicle	250.0	173.6	-76.4
Ground Systems	N/A	N/A	N/A
Science/Technology	1.3	2.8	1.5
Other Direct Project Costs	101.9	63.4	-38.5

Project Management & Commitments

GSFC has program management responsibility for the LWS program and the SOC project. NASA procured all instruments provided by the United States through a competitive AO.

SOLAR ORBITER COLLABORATION

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
SoloHI	Measures the solar wind formations, shock disturbance, and turbulence.	Provider: Naval Research Lab Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
HIS	Measures the range of heavy ion energies, charge states, masses, and elevation angles as part of the United Kingdom-provided Solar Wind Analyzer instrument suite.	Provider: SwRI Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Expendable Launch Vehicle	Launch vehicle	Provider: ULA Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: ESA hardware delivery for launch is delayed, Then: NASA launch vehicle and development costs will increase.	Monitor ESA's progress during its hardware development and maintain frequent communication between NASA and ESA at all levels of management.

Acquisition Strategy

NASA selected the instruments and science investigations from a competed AO. NASA competitively selected the launch vehicle through the NASA Launch Services-II contract.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
SoloHI	Naval Research Lab	Washington, DC
HIS	SwRI	San Antonio, TX

SOLAR ORBITER COLLABORATION

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Nov 2012	PDR to assess readiness for KDP-C	Successful, project ready to proceed to development	Sept 2013
Performance	SRB	Sept 2013	SoloHI Instrument to assess readiness for CDR	Successful	Mar 2014
Performance	SRB	Mar 2014	HIS Instrument to assess readiness for CDR	Successful	Mar 2017
Performance	SRB	Mar 2017	Pre-ship Review to assess readiness for shipment to ESA	Successful	TBD
Performance	SRB	TBD	Operations Readiness Review/Mission Readiness Review to assess readiness for KDP-E	TBD	

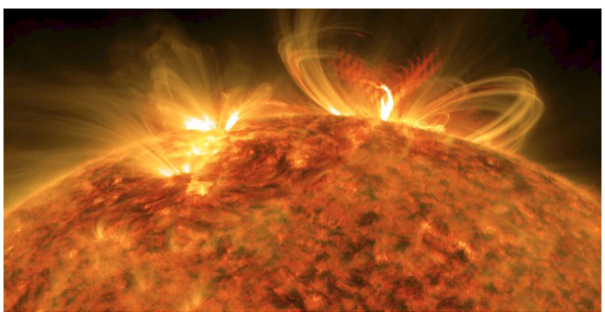
OTHER MISSIONS AND DATA ANALYSIS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
LWS Space Environment Testbeds	0.7	--	**0.5**	0.0	0.0	0.0	0.0
LWS Science	23.8	--	**38.5**	38.4	35.3	35.3	35.3
LWS Program Management and Future Missions	6.2	--	**14.2**	9.3	9.9	19.4	55.8
Van Allen Probes (RBSP)	13.3	--	**13.0**	9.0	0.0	0.0	0.0
Solar Dynamics Observatory (SDO)	12.1	--	**12.0**	12.0	12.0	12.0	11.2
Total Budget	**56.0**	--	**78.2**	**68.7**	**57.2**	**66.7**	**102.3**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



While the Sun's 11-year activity cycle is currently going toward its minimum, September 2017 saw a spate of some of the most intense activity observed in the current solar cycle. This image shows a Sept. 10, 2017, solar flare as observed by NASA's Solar Dynamics Observatory. This flare is classified as an X8.2-class flare. X-class denotes the most intense flares, while the number provides more information about its strength. Harmful radiation from a flare cannot pass through Earth's atmosphere to physically affect humans on the ground, however — when intense enough — they can disturb the atmosphere in the layer where GPS and communications signals travel.

The LWS Other Missions and Data Analysis budget includes operating LWS missions, a science research program, program management, and funding for missions to launch in the next decade.

For more information, go to http://science.nasa.gov/about-us/smd-programs/living-with-a-star/.

Mission Planning and Other Projects

LWS SPACE ENVIRONMENT TESTBEDS

The Space Environment Testbeds (SET) project seeks to improve the accommodation and/or mitigation of the effects of solar variability on spacecraft. It addresses the identification and understanding of the mechanisms of space environment interactions, modeling of these interactions, and development and validation of ground test protocols to qualify technologies for space. As the complexity of the technologies increases, models derived from the physics-based understanding of the effects are required, and the SET mission responds to these needs. The SET mission will reach medium-Earth orbit as a rideshare payload on the

OTHER MISSIONS AND DATA ANALYSIS

Air Force Research Laboratory's (AFRL's) Demonstration and Space Experiments (DSX) spacecraft, with the launch expected no earlier than early 2018.

Recent Achievements

In anticipation of the upcoming launch of the Air Force Research Laboratory (AFRL) DSX spacecraft on a SpaceX Falcon Heavy, AFRL recently attended the STP-2 (Space Test Program-2) Ground Operations Working Group at Cape Canaveral Air Force Station. The AFRL DSX spacecraft contains the SET payload. SpaceX scheduled three upcoming launches of the Falcon Heavy launch vehicle starting in December 2017. The third launch of the Falcon Heavy includes the DSX spacecraft with the SET payload; the scheduled launch date is April 30, 2018 with a two-month window extending out to June 30, 2018.

LWS SCIENCE

Understanding space weather and improving the capability to address problems, such as predicting geomagnetic storms, pose two major challenges for the research community. First, research must couple traditionally separate disciplines in heliophysics, such as solar-heliospheric and geospace physics. Second, to be truly successful, research must also demonstrate how results would enhance an operational capability, such as the generation of forecasts for geomagnetic storms.

LWS Science addresses these challenges through three main approaches:

- Builds expertise: This component includes funding to train the next generation of heliophysics experts, conduct a heliophysics graduate-level summer school, develop graduate course content, and support a limited number of space weather postdoctoral positions at universities and government laboratories;
- Addresses scientific needs: The goal of the project is to develop the scientific understanding needed for the United States to address those aspects of heliophysics that may affect life and society. To ensure this, the targeted research element solicits large-scale problems that cross discipline and technique boundaries.
- Addresses strategic capabilities: A primary goal of this project is the development of first-principles-based models for the coupled Sun-Earth and Sun-solar system, similar to the first-principles models for the lower terrestrial atmosphere. Such models can act as tools for science investigations, as prototypes and test beds for prediction and specification capabilities, as frameworks for linking disparate data sets at vantage points throughout the Sun-solar system, and as strategic planning aids for enabling exploration of space and testing new mission concepts.

Recent Achievements

Recent LWS Focused Science Topic studies produced significant progress in heliophysics by examining fundamental chemical and physical processes and expanding modeling capabilities to include them. The investigation into how the Earth's atmosphere responds to impulsive solar events (ISE) addressed four primary questions: 1) How well do coupled chemistry climate models simulate effects of recent ISEs? 2) What are the primary factors that control the atmospheric response to ISEs? 3) What is the range and sensitivity of the atmospheric response to ISEs? 4) Are there long-term, cumulative effects of ISEs on the atmosphere and climate, and with what certainty can researchers model these effects? This research answered these questions by using the Community Earth System Model, version 1 (CESM1), which is a coupled climate model for simulating the Earth's climate system. Four separate models compose CESM1 that simultaneously simulates the earth's atmosphere, ocean, land surface, and sea-ice. The atmospheric model is the Whole Atmosphere Community Climate Model (WACCM), Version 4. WACCM and WACCM-X provide a comprehensive numerical model spanning the altitude range from the Earth's surface, to the thermosphere up to 400 km.

This study addressed the sensitivity of ISEs to different atmospheric states, model simulations with solar input from the Flare Irradiance Spectral Model (FISM), model simulations with new Miniature X-ray Solar Spectrometer (MinXSS) solar soft X-ray observation-based input, atmospheric effects following several solar storms, atmospheric effects due to galactic cosmic rays, energetic particle precipitation, solar proton events, solar flares, and 27-day solar variability, and flare-induced traveling ionospheric disturbances. The results of this study clarify the role of a broad range of solar inputs to the terrestrial atmospheric system, and produced improved ability to model these effects.

Other studies examined the properties of solar flares and coronal mass ejection (CME) activities at high solar latitudes using SDO data. The primary scientific question addressed during the performance period was: Are polar-crown coronal mass ejections (CMEs) similar to the low-latitude counterparts in kinematics, morphology, energetics, and relationship with flares? Answering this question is important in understanding solar eruptions from closed field regions of the Sun, irrespective of the source location. While CMEs at low latitudes are common in both active regions and quiescent filament regions, the occurrence of high-latitude CMEs from polar crown filament region required additional study. This research showed that the high-latitude (or polar) CMEs are indeed similar to their low-latitude counterparts, thus providing a unified understanding of the eruption process. This investigation supports the view that closed field regions magnetically propel all CMEs, irrespective of their location on the Sun (polar crown filament regions, quiescent filament regions, or active regions).

Additional research examined the seed particle populations in the solar corona associated with Solar Energetic Events (SEP) events. These results provided observational verification of a pump acceleration mechanism. The specific output of the pump acceleration mechanism is a power law spectrum in particle speed, with spectral index of -5, when expressed as a distribution function, known as the common spectrum. This work showed that the common spectrum occurs downstream from shocks that contain compressive turbulence. These observations provide a validation of the pump acceleration mechanism, and illustrate the conditions in which it applies, and thus serve as the basis for applying the pump acceleration mechanism in the solar corona.

LWS PROGRAM MANAGEMENT AND FUTURE MISSIONS

Program Management and Future Missions provide the resources required to manage the planning, formulation, and implementation of all LWS missions. The office resolves technical and programmatic issues and risks, monitors and reports on progress, and is responsible for achieving overall LWS cost and schedule goals. In addition, Future Missions support strategic planning for addressing the LWS recommendations of the Heliophysics decadal survey, and the pre-formulation activities for missions that are still merely concepts.

Recent Achievements

The next LWS mission identified by the Heliophysics Decadal Survey is the Geospace Dynamics Constellation (GDC). The primary objective of GDC is to "characterize and understand how the ionosphere-thermosphere behaves as a system, responding to, and regulating, solar wind/magnetospheric energy input." This mission will provide crucial understanding of the processes that govern the interactions between the solar wind that continually streams from the sun, and the Earth's upper atmosphere. These interactions affect the conditions and variability of the upper atmosphere that, in turn, impact the properties of a broad range of phenomena that range from natural geomagnetic events to the ionospheric effects on communication and navigation.

NASA is taking several steps in support of this upcoming opportunity. During FY 2017, NASA initiated a call for membership in the GDC Science and Technology Definition team (STDT). In addition, NASA issued an RFI to solicit input from the Heliophysics community for ideas on mission and technology concepts to address the GDC objectives and science goals as well as enhance those concepts outlined for GDC in the Decadal Survey. NASA has scheduled the start of the STDT for early 2018 with a completion date and final report due in late 2018.

Operating Missions

VAN ALLEN PROBES

The Van Allen Probes mission is helping scientists to understand the Sun's influence on Earth and near-Earth space by studying Earth's radiation belts on various scales of space and time. The mission observes the processes that energize and transport radiation belt electrons and ions in Earth's inner magnetosphere, the area in and around Earth's radiation belts. These observations are providing new knowledge on the dynamics and extremes of the radiation belts that are important to all technological systems that fly in and through geospace. The mission will enable an understanding, ideally to the point of predictability, of how populations of relativistic electrons and penetrating ions in space form or change in response to variable inputs of energy from the Sun.

Recent Achievements

The magnetospheric community used Van Allen observations to make several recent discoveries about the complex dynamic evolution of the radiation belts. Van Allen observations showed that ultra-low frequency waves produced an extended dropout event, observed as an unusually long electron radiation belt flux dropout event that extended more than 10 days. This study focused on the recovery of the fluxes in the outer belt and what delayed these fluxes so long even with continued solar wind forcing. Simulations of this dropout event included several interactions and transport of electrons. The results showed that ultra-low frequency waves produced the extended depletion.

Other observations showed the impact of powerful very-low frequency transmitters over a 4-year period (2012-2016) on the radiation belts. Wave simulations based on this information demonstrated the crucial impact of these anthropogenic waves on electron radiation belt loss at $L<2.5$.

In other studies, scientists used a comprehensive set of Van Allen observations to understand ultra-relativistic electron loss driven by various mechanisms. By examining the energy spectrum of electrons extending up to relativistic energies they were able to determine the balance between acceleration and loss processes in the radiation belts. Relativistic electrons were enhanced while ultra-relativistic electrons were significantly depleted. These researchers compared simulations and observations to demonstrate that electrons at ultra-relativistic energies were responsible for this dropout.

OTHER MISSIONS AND DATA ANALYSIS

These and other recent discoveries show the progress in understanding processes in the magnetosphere made with the help of the Van Allen Probes mission.

SOLAR DYNAMICS OBSERVATORY (SDO)

Launched on February 11, 2010, the SDO seeks to understand the Sun's influence on Earth and near-Earth space by simultaneously studying the solar atmosphere on small scales of space and time and in many wavelengths. The observatory enables scientists to determine how the Sun's magnetic field is generated and structured and how stored magnetic energy is converted and released in the form of solar wind, energetic particles, and variations in the solar irradiance. SDO collects data to help explain the creation of solar activity, which drives space weather. Measurements of the interior of the Sun, the Sun's magnetic field, the hot plasma of the solar corona, and the irradiance that creates Earth's ionosphere are the primary data products.

Recent Achievements

SDO investigations made significant progress on mission science questions and the SDO science investigation teams have achieved all of the original observing objectives of the mission. Studies related to SDO have led to the publication of over 2600 refereed papers (about 500 publications per year), about 50 PhD dissertations, and over 1000 conference papers. Three research projects from SDO observations show the range of important results.

1) A recent study analyzed sequences of images from AIA, HMI and other observations, and determined the wave properties around a sunspot as a function of altitude. They could follow the waves from the photosphere through the chromosphere and into the corona. The wave paths are not vertical, but tilt away from the sunspot at the center of the images. Changes in the wave field as it moves upward determine the strength and direction of the magnetic field. This novel application of analysis techniques traditionally used on observations of the coupled photosphere-chromosphere-transition region-corona system for seismology of the solar interior demonstrates how SDO continues to enable leading edge science.

2) Researchers often observe coronal dimming after solar eruptions even though different physical processes can generate them. For space weather, the temporary void left by a coronal mass ejection (CME) is the most important property. Fast, massive CMEs tend to leave behind a darker void. If the darkening is associated with a solar flare, the light curve in the cooler emission can be isolated and removed using warmer coronal emissions. Researchers analyzed 37 events during two separate periods to parameterize coronal dimming in terms of the depth of the dimming and the slope of the decreasing irradiance. They determined the best linear relationships are between the velocity of the CME and the slope of the observed dimming and between the mass of the CME and the square root of the depth of the dimming.

3) Finally, coronal cavities are dark regions found above filaments on the solar surface that resemble tunnels through the corona. They have a dark core and bright edges. Several researchers used SDO data to study the evolution of coronal cavities in time and space. Coronal cavities correlate with the rise to solar maximum. As magnetic flux from the new cycle rises and disperses, some moves poleward and encounters the remnant flux from the previous cycle. A filament forms across the neutral line between these regions of opposite-polarity magnetic field. As this filament moves poleward, it tends to have a cavity, even though few other filaments do. After the old polar field disappears, cavities appear on filaments throughout the Sun. Researchers have seen the poleward migration of filaments before, but the

region between the migrating filament and the equator was dense with filaments. Measurements of the cavity of the persistent polar crown filament showed that eruptions destroyed it.

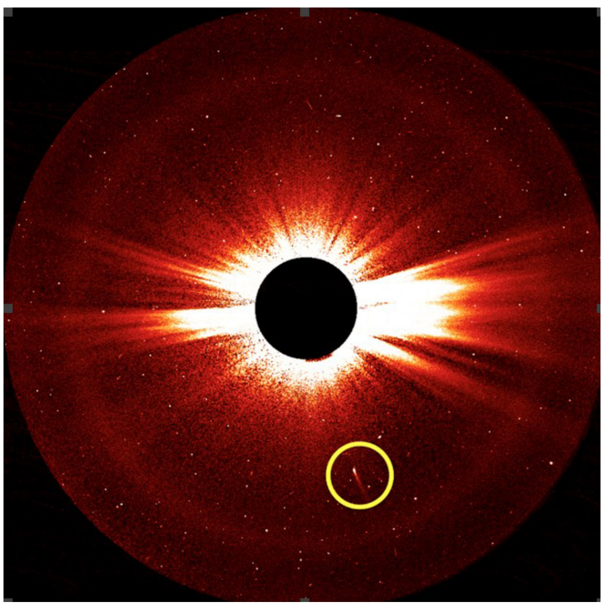
SOLAR TERRESTRIAL PROBES

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Other Missions and Data Analysis	38.8	--	**91.0**	89.9	177.7	175.6	247.9
Total Budget	**38.8**	**--**	**91.0**	**89.9**	**177.7**	**175.6**	**247.9**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



STEREO — short for Solar and Terrestrial Relations Observatory —watched Comet 96P orbit around the Sun on October 26-28, 2017, from its vantage point on the far side of the Sun. These images joined others from the joint ESA/NASA Solar and Heliospheric Observatory, or SOHO. It is extremely rare for comets to be seen simultaneously from two different locations in space, and these are the most comprehensive parallel observations of comet 96P yet. Scientists are eager to use these combined observations to learn more about the comet's composition, as well as its interaction with the solar wind, the constant flow of charged particles from the Sun.

The Solar Terrestrial Probes (STP) program focuses on understanding the fundamental physical processes of the space environment, from the Sun to the Earth, other planets, and beyond to the interstellar medium. STP provides insight into the basic processes of plasmas (fluid of charged particles) inherent in all astrophysical systems. STP missions focus on processes such as the variability of the Sun, responses of the planets to those variations, and the interaction of the Sun and the solar system. NASA defines specific goals for STP missions and selects investigations for each mission competitively. These missions allow the science community an opportunity to address important research focus areas and make significant progress in understanding fundamental physics.

For more information, go to http://science.nasa.gov/about-us/smd-programs/solar-terrestrial-probes/.

EXPLANATION OF MAJOR CHANGES IN FY 2019

An increase in STP Program Management and Future Missions will fund seven months of Phase A studies from the STP-5 AO as well as five months of costs for Phase B for the selected mission. It will also fund part of the cost of an ESPA ring, Phase A studies for the upcoming Heliophysics Science MoO and Technology Demonstration MoO.

SOLAR TERRESTRIAL PROBES

The launch of MMS was delayed by six months, through no fault of the project, so that their prime launch window was not met. As a result, the project has been doing a catch-up to recover the day-side science. The increase will allow MMS to meet fully its Level 1 science requirements, and to plan the transition to an extended mission phase.

ACHIEVEMENTS IN FY 2017

MMS completed Prime Operations and moved to extended operations. NASA released an AO for the STP-5 mission in FY 2017, named the Interstellar Mapping and Acceleration Probe (IMAP) mission in the 2013 Heliophysics decadal survey. IMAP will provide observations that will help us understand the global processes that act in the boundary in which the solar wind and the interstellar medium interact, which is the main barrier that shields the solar system against galactic cosmic rays. It will furthermore directly advance understanding of particle acceleration processes, knowledge that may become essential in reducing radiation exposure of astronauts on exploration missions.

WORK IN PROGRESS IN FY 2018

Operations of the MMS, STEREO, Hinode, and TIMED missions continue. NASA plans to award Phase A (Concept and Technology Development) study contracts for IMAP, for a period of twelve months. NASA plans to release a Mission of Opportunity (MO) Program Element Appendix (PEA, solicitation), as well as a PEA for a Technology Development MO.

NASA and NOAA are exploring a potential partnership to use the same launch vehicle for IMAP and a NOAA space weather monitoring payload. The partnership would provide NOAA access to the L1 Lagrange point for future space weather monitoring.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

NASA plans to select to a single Principal Investigator to enter into Phase B (Preliminary Design and Technology Completion) of the IMAP mission. NASA also plans to select and enter into Phase B for the STP-Funded Mission of Opportunity.

Program Schedule

Date	Significant Event
FY 2017	AO for IMAP Mission
FY 2018	IMAP Phase A studies selection and MO release
FY 2019	IMAP KDP-B

Program Management

GSFC manages the STP program.

Acquisition Strategy

In the acquisition of STP scientific instruments, spacecraft, and science investigations (including Research and Analysis), NASA will use full and open competitions to the greatest extent possible. NASA may acquire certain instruments, missions, or mission systems without competition (e.g., through international partnerships or in-house builds), if there is a clear scientific, technological, or programmatic benefit to NASA to do so. NASA will acquire launch vehicles through existing contracts, managed by the HEOMD, except when an international partner provides them under an approved agreement.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Independent Review	SRB	Nov 2014	Assess performance of program	Successful	Sept 2018
Program Independent Review	SRB	Sept 2018	Assess performance of program		

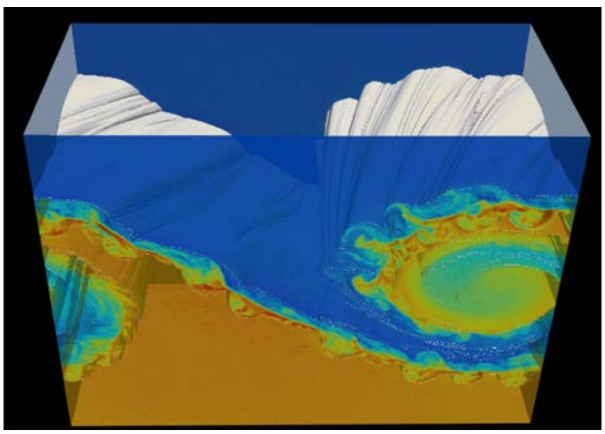
OTHER MISSIONS AND DATA ANALYSIS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
STP Program Management and Future Missions	2.8	--	**56.2**	55.0	145.9	143.6	228.7
Magnetospheric Multiscale (MMS)	19.9	--	**17.0**	17.0	15.0	15.0	4.0
Solar Terrestrial Relations Observatory (STEREO)	6.5	--	**8.3**	8.3	7.3	7.3	6.5
Hinode (Solar B)	7.0	--	**7.0**	7.0	7.0	7.0	6.3
TIMED	2.6	--	**2.6**	2.6	2.5	2.7	2.4
Total Budget	**38.8**	**--**	**91.0**	**89.9**	**177.7**	**175.6**	**247.9**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



This visualization of the boundary between Earth's magnetic fields and the space that surrounds it is based on observations from the Magnetospheric Multiscale, or MMS, mission. MMS spotted Kelvin Helmholtz waves – which look like crashing ocean waves -- along this boundary, which can allow particles from the solar wind to enter near-Earth space.

The STP Other Missions and Data Analysis budget includes operating STP missions, program management, and funding for future missions launching in the next decade.

For more information, go to http://stp.gsfc.nasa.gov.

Mission Planning and Other Projects

PROGRAM MANAGEMENT AND FUTURE MISSIONS

Program Management and Future Missions provide the resources required to manage the planning, formulation, and implementation of all STP missions. The program office ensures successful achievement of STP program cost and schedule goals, while managing cross-project dependencies, risks, issues, and requirements as projects progress through formal key decision points. In addition, Future Missions supports the STP program strategic planning for addressing the recommendations of the Heliophysics Decadal Survey and the pre-formulation activities for STP missions not yet approved as projects.

OTHER MISSIONS AND DATA ANALYSIS

Operating Missions

MAGNETOSPHERIC MULTISCALE (MMS)

The MMS mission investigates how the magnetic fields of the Sun and Earth connect and disconnect, explosively transferring energy from one to the other. This magnetic reconnection process occurs throughout the universe. MMS uses Earth's magnetosphere as a natural laboratory to study the microphysics of magnetic reconnection, a fundamental plasma-physical process that converts magnetic energy into heat and charged particle kinetic energy. In addition to seeking to solve the mystery of the small-scale physics of the reconnection process, MMS will investigate how the energy conversion that occurs in magnetic reconnection accelerates particles to high energies and what role plasma turbulence plays in reconnection events. Magnetic reconnection, particle acceleration, and turbulence occur in all astrophysical plasma systems, but researchers can only study them in-situ in the solar system, and most efficiently in Earth's magnetosphere, where these processes control the dynamics of the geospace environment and play an important role in the phenomena known as space weather.

The MMS mission consists of four identically instrumented spacecraft that measure particles, fields, and plasmas. The MMS instrument payload measures electric and magnetic fields and the plasmas found in the regions where magnetic reconnection occurs. Fast, multi-point measurements are enabling dramatically revealing direct observations of these physical processes. A highly elliptical orbit explores how Sun-Earth magnetic fields reconnect in Earth's neighborhood. The four spacecraft fly in a tetrahedron formation that allows them to observe the three-dimensional structure of magnetic reconnection events. The separation between the observatories is adjustable over a range of six to 250 miles during science operations in the area of interest.

For more information, go to http://science.nasa.gov/missions/mms/.

Recent Achievements

Electrons in a strong magnetic field usually exhibit a simple behavior: they spin tight spirals along magnetic field lines. In a weaker field region, where the direction of the magnetic field reverses, the electrons move more freely — bouncing and swaying back and forth in a type of movement called Speiser motion. New MMS results show, for the first time, what happens in an intermediate strength field. Electrons in these field strengths move in a hybrid, meandering motion — spiraling and bouncing about before ejecting from the region. This motion takes away some of the field's energy and plays a key role in magnetic reconnection – a dynamic process, which can explosively release large amounts of stored magnetic energy. As MMS flew around Earth, it passed through an area of a moderate strength magnetic field where electric currents run in the same direction as the magnetic field, known as intermediate guide fields. While inside the region, the instruments recorded a curious interaction of electrons with the current sheet, the thin layer through which the current travels. As the incoming particles encountered the region, they started gyrating in spirals along the guide field – as they do in a strong magnetic field – but in larger spirals. The MMS observations saw signatures of the particles gaining energy from the electric field. Before long, the accelerated particles escaped the current sheet, and formed high-speed jets. In the process, they took away some of the field's energy, and caused it to gradually weaken. The new results help scientists better understand the role of electrons in reconnection, and how magnetic fields lose energy. With four spacecraft flying in a compact, pyramid formation, MMS is able to see fields and particles in three dimensions and look at small-scale particle dynamics in a way never before achieved.

OTHER MISSIONS AND DATA ANALYSIS

SOLAR TERRESTRIAL RELATIONS OBSERVATORY (STEREO)

STEREO enables studies of the origin of the Sun's CMEs and their consequences for Earth, other planets, and interplanetary space. The mission consists of two spacecraft, one (STEREO-A) Ahead and the other (STEREO-B) Behind Earth in its orbit. STEREO's instrumentation targets the fundamental process of energetic particle acceleration in the low solar corona and in interplanetary space. The mission can image the structure and evolution of solar storms as they leave the Sun and move through space toward Earth. The mission also provides the foundation for understanding space weather events and developing predictive models. The models in turn, help to identify and mitigate the risks associated with space weather events. In addition, STEREO improves our space weather situational awareness not only for Earth and in low Earth orbit, but also throughout the solar system.

On October 1, 2014, NASA lost communication with STEREO-B, just as the spacecraft was about to orbit around the other side of the Sun. In late 2015, the spacecraft finally emerged from behind the Sun. NASA re-established contact with STEREO-B for a short period in 2016. NASA made several attempts to establish control of the spacecraft with limited success. As of December 2017, the project team will make monthly attempts to re-establish contact with the spacecraft. STEREO-A continues to operate nominally and is still providing significant science data.

Recent Achievements

New research using data from the NASA Heliophysics STEREO A, B and SDO missions has revealed information about the sun that enables a new approach to developing predictive capabilities for space weather events. Scientists tracked coronal brightpoints — small, luminous features observed on the sun directly tied to magnetic activity beneath the surface. Trains of brightpoints circled the sun slowly, moving westward and revealing the magnetized Rossby waves flowing beneath the surface. Rossby waves are a type of inertial wave driven by the physical properties of a planet's, or in this case, the sun's rotation. The identification of the Rossby waves was only made possible through the use of 360-degree images of the Sun constructed by combining images from the STEREO satellites, in orbit ahead and behind the Earth, with SDO images over a three-year period from 2010 to 2013. Rossby waves are responsible for day-to-day weather patterns at mid-latitudes as they form high and low-pressure systems. An important question is whether Rossby waves play a similar role in space weather events originating on the sun. Applying what we know about how Rossby waves behave on Earth may help us understand solar Rossby waves and the interior process that drive them, which is an important step towards the development of long-term space weather forecasting.

HINODE

Hinode is a joint JAXA and NASA mission, operating as a follow-on to the highly successful Japan, United States, and United Kingdom Yohkoh (Solar-A) collaboration. The mission consists of a coordinated set of optical, extreme ultraviolet, and X-ray instruments that are studying the basic heating mechanisms and dynamics of the active solar corona. By investigating the fundamental processes that connect the Sun's magnetic field and the solar corona, Hinode is discovering how the Sun generates magnetic disturbances and the high-energy particle storms that propagate from the Sun to Earth.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

Most research has gone into investigating how magnetic topology on the Sun creates favorable conditions for eruptions, however, on September 30, 2014, multiple NASA observatories, including Hinode viewing in dozens of different wavelengths, watched as a filament rose from the surface, gaining energy and speed but instead of erupting from the Sun as expected, the filament weakened and collapsed. The observations in multiple wavelengths revealed conditions on the Sun's surface and in its lower atmosphere during the event. It appeared that the filament had encountered a magnetic boundary that prevented its eruption. Typically, when solar structures with opposite magnetic orientations collide, they explosively release magnetic energy, heating the atmosphere with a flare and erupting into space as a coronal mass ejection — a massive cloud of solar material and magnetic fields. But on the day of the September 2014 near-eruption, the filament instead pushed up against a complex magnetic structure, shaped like two igloos smashed against each other. This invisible boundary, called a hyperbolic flux tube, was the result of a collision of two bipolar regions on the sun's surface. Evidence suggest that the hyperbolic flux tube broke the filament's magnetic field lines reconnecting them with those of the ambient Sun, so that the filament's magnetic energy was stripped away, effectively prevented the eruption from proceeding. This study indicates the Sun's magnetic topology plays an important role in whether or not an eruption occurs.

THERMOSPHERE, IONOSPHERE, MESOSPHERE ENERGETICS AND DYNAMICS (TIMED)

The TIMED mission characterizes and studies the physics, dynamics, energetics, thermal structure, and composition of the least explored and understood region of Earth's atmosphere, the mesosphere-lower thermosphere-ionosphere (MLTI). This region of interest, located between altitudes of approximately 35 to 100 miles above the surface of Earth, helps protect Earth from harmful solar radiation. It is a gateway between Earth's environment and space, where the Sun's energy first affects Earth's environment.

Recent Achievements

The TIMED satellite revealed a significant population of hot hydrogen atoms at altitudes as low as 170 miles, much lower than previously expected. A comprehensive analysis of the TIMED data (which now spans more than a solar cycle) showed that the temperature of this atomic hydrogen rises when solar activity falls, counter to the behavior of most other neutral molecules in the atmosphere. Atomic hydrogen, the dominant neutral constituent of the upper layer of Earth's atmosphere, is key to understanding many aspects of atmospheric chemistry, energetics, and ion-neutral coupling with the plasmasphere and magnetosphere. Atomic hydrogen is also the lightest neutral species, requiring the least amount of energy to escape Earth's gravitational force. A lot of attention has been given, and will continue to be given, to understanding the processes that lead to hydrogen loss from the atmosphere.

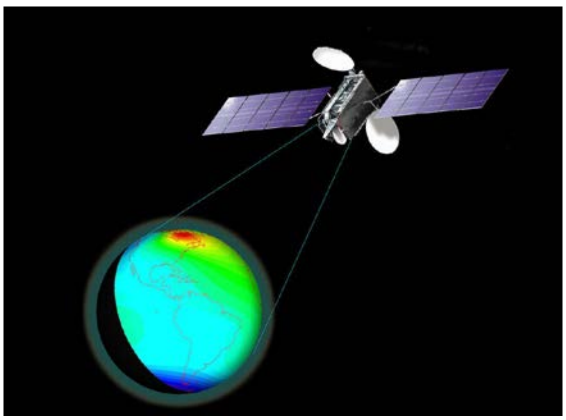
HELIOPHYSICS EXPLORER PROGRAM

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Other Missions and Data Analysis	86.7	--	**109.2**	263.1	202.9	204.1	94.4
Total Budget	**86.7**	**--**	**109.2**	**263.1**	**202.9**	**204.1**	**94.4**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



NASA's Global-scale Observations of the Limb and Disk, or GOLD, mission explores a little understood area close to home, but historically hard to observe: the lowest reaches of space, a dynamic area in Earth's upper atmosphere that responds both to space weather above, and the lower atmosphere below. GOLD collects observations with a 30-minute cadence, much higher than any mission that has come before it. This enables GOLD to be the first mission to study the day-to-day weather of upper atmosphere –the overlapping thermosphere and the ionosphere -- rather than its long-term climate.

The Heliophysics Explorer Program provides frequent flight opportunities for world-class scientific investigations on focused and timely science topics. Explorers use a suite of smaller, fully competed missions that address these topics to complement the science of strategic missions of the LWS and STP programs. Competitive selections ensure accomplishment of the most current and best science.

The Explorers Program provides several classes, Medium Explorers (MIDEX) and Small Explorers (SMEX), of flight opportunities to accomplish the goals of the science program. These mission classes enable NASA to increase the number of flight opportunities in response to recommendations from the scientific community.

The 2011 NASA AO introduced a new class of flight opportunity, the Explorers (EX) missions, in response to the currently available expendable launch vehicles. EX missions fall between the SMEX and MIDEX class missions. Awarded missions will utilize one of the several, lower-cost expendable launch vehicles available through NASA's Launch Services Program.

Explorer Missions of Opportunity (MO) are smaller investigations, typically an instrument, characterized as being part of a host space mission, sub-orbital flight, small complete missions, and new science investigations using existing spacecraft or ISS-attached payloads.

Other Missions and Data Analysis supports numerous operating Heliophysics Explorer missions, as well as program management functions and funding for future mission selections.

HELIOPHYSICS EXPLORER PROGRAM

For more information on Explorer missions, go to https://science.nasa.gov/about-us/smd-programs/explorers/.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

On July 28, 2017, NASA under the Heliophysics Announcement of Opportunity (AO) selected proposals, five Heliophysics Small Explorer missions and two Explorer Missions of Opportunity, for concept studies. These studies will span a broad range of investigations focusing on terrestrial weather in the near-Earth space environment; magnetic energy; solar wind; and heating and energy released in the solar atmosphere.

WORK IN PROGRESS IN FY 2018

Missions selected for SMEX and MO Phase A concept studies will deliver their reports to NASA for evaluation in early summer 2018. NASA will launch the ICON and GOLD missions.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

NASA will make new mission selections from competitive concept studies (Phase A) for the SMEX and MO AO.

Program Schedule

Date	Significant Event
Early Summer 2018	Down select at least one SMEX and one MO mission for implementation
FY 2018	AO announcement for MIDEX and MO opportunity to propose
FY 2020	MIDEX and Explorer MO Phase-A selections
FY 2021	Down select one MIDEX and one MO mission for implementation

HELIOPHYSICS EXPLORER PROGRAM

Program Management & Planned Cadence

The Heliophysics and Astrophysics Explorer elements are both coordinated sets of uncoupled missions, wherein each mission is independent and has unique science, and share a common program office at GSFC and a common management structure. The Explorer program manager resides at GSFC, reporting functionally to the Center Director and programmatically through the Heliophysics and Astrophysics Division Directors to the Associate Administrator for SMD.

This budget brings the Heliophysics Explorer Program into alignment with the Decadal Survey's recommendation of a two-to-three year mission cadence.

Acquisition Strategy

NASA competitively selects new Explorer missions, releasing solicitations when available funding allows, with the expectation of a three-year cadence. NASA acquires launch vehicles through existing contracts held by the HEOMD, except when an international partner provides them under an approved agreement or when the Explorer mission is not a primary payload on the launch vehicle.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Independent Review	SRB	Nov 2014	Assess performance of program	Successful	Oct 2019

IONOSPHERIC CONNECTION EXPLORER (ICON)

Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Prior	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023	BTC	Total
Formulation	38.8	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	38.8
Development/Implementation	149.6	36.8	9.5	**0.0**	0.0	0.0	0.0	0.0	0.0	196.0
Operations/Close-out	0.0	2.6	9.4	**4.5**	1.3	0.0	0.0	0.0	0.0	17.9
2018 MPAR LCC Estimate	**188.4**	**39.4**	**19.0**	**4.5**	**1.3**	**0.0**	**0.0**	**0.0**	**0.0**	**252.7**
Total Budget	**188.4**	**39.4**	**19.0**	**4.5**	**1.3**	**0.0**	**0.0**	**0.0**	**0.0**	**252.7**
Change from FY 2018				**-14.5**						
Percentage change from FY 2018				**-76.3%**						

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Recent discoveries show that unexplained variations in Earth's space environment are connected to conditions in the atmosphere. NASA's Ionospheric Connection Explorer, or ICON, is the first mission to focus on this interplay between terrestrial weather and space weather. ICON explores a little understood area close to home, but historically hard to observe: a region of the upper atmosphere called the ionosphere. The mission focuses on one of the most eye-catching phenomena there, colorful bands called airglow, which can be seen over the horizon in this artist's rendition of ICON in space.

PROJECT PURPOSE

Ionospheric Connection Explorer (ICON) is a single spacecraft mission dedicated to understanding neutral-ion coupling in the Earth's upper atmosphere, also known as the thermosphere. It will resolve both long-standing and newly emerging questions about the mechanisms that control the daily development of plasma in Earth's space environment.

EXPLANATION OF MAJOR CHANGES IN FY 2019

Due to issues involving the Pegasus launch vehicle's bolt cutter assembly, the launch provider is in the process of rescheduling the launch readiness date, originally scheduled in October 2017, to a later date in FY 2018. The launch delay will cause the mission on-orbit operations to start later than planned.

IONOSPHERIC CONNECTION EXPLORER (ICON)

Formulation	Development	Operations

PROJECT PARAMETERS

ICON will simultaneously measure altitude profiles of the thermosphere and ionosphere's neutral winds, composition, density, temperature, and ion density. At the same time, it will make in-situ plasma measurements. Three institutions with a successful record of accomplishment of previous space missions will build the four high-heritage scientific instruments of ICON. The payload will fly on an Orbital ATK, LEOStar-2 spacecraft bus with heritage from Solar Radiation and Climate Experiment (SORCE), AIM, Orbiting Carbon Observatory (OCO), Glory, and Nuclear Spectroscopic Telescope Array (NuSTAR). ICON will provide the data to "understand how neutral winds control ionospheric variability," which is a goal in the 2010 Science Plan for NASA's SMD.

ACHIEVEMENTS IN FY 2017

During this period, the ICON project successfully conducted the Observatory Pre-Environment Review (PER) on January 1, 2017; Operation Readiness Review (ORR) on April 6, 2017; and Observatory Pre-Ship Review (PER) on July 19, 2017.

WORK IN PROGRESS IN FY 2018

The Project will complete all observatory testing and prepare the spacecraft for shipping. The Project will ship the spacecraft for integration to the launch vehicle at Vandenburg Air Force Base (VAFB). NASA plans to launch ICON in FY 2018 to begin a two-year prime mission. Due to issues involving the Pegasus launch vehicle's Bolt Cutter Assembly, the launch provider, Orbital ATK, is in process of rescheduling the launch readiness date in FY 2018.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

In FY 2019, ICON will complete its first full year of operations.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2019 PB Request
KDP-C	Oct 2014	Oct 2014
CDR	Apr 2015	Apr 2015
SIR	Jun 2016	Aug 2016
Launch	Oct 2017	2018
Start of Phase E	Nov 2017	2018
End of Prime Mission	Dec 2019	2020

IONOSPHERIC CONNECTION EXPLORER (ICON)

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2015	196.0	70	2018	196.0	0.0	LRD	Oct 2017	2018	TBD

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

NASA confirmed ICON to proceed into implementation in October 2014.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**196.0**	**196.0**	**0.0**
Aircraft/Spacecraft	29.8	47.9	18.1
Payloads	35.8	45.0	9.2
Systems I&T	9.4	3.3	-6.1
Launch Vehicle	54.3	56.3	2.0
Ground Systems	2.9	5.6	2.7
Science/Technology	3.0	4.0	1.0
Other Direct Project Costs	60.8	33.9	-26.9

IONOSPHERIC CONNECTION EXPLORER (ICON)

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Expendable Launch Vehicle	Deliver the spacecraft to operational orbit	Provider: Orbital-ATK Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): n/a	N/A
Spacecraft	Transport instruments to science destination	Provider: Orbital ATK Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): n/a	N/A
Michelson Interferometer for Global High-resolution Thermospheric Imaging (MIGH TI)	High resolution imager instrument	Provider: Naval Research Laboratory Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s):	N/A
EUV	Extreme UV instrument	Provider: University of California, Berkeley Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s):	N/A
FUV	Far UV instrument	Provider: University of California, Berkeley Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): Belgian Centre Spatial de Liège (CSL)	N/A
IVM	Ion velocity meter instrument	Provider: University of Texas, Dallas Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s):	N/A

IONOSPHERIC CONNECTION EXPLORER (ICON)

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: A Pegasus Launch Vehicle Bolt Cutter Assembly (BCA) fails a margin demonstration test to ensure there is enough energy to successfully fracture a bolt that is 20 percent larger than the normal bolt size used. Then: The ICON mission will be further delayed, potentially 6 months beyond the baseline commitment of October 2017	NASA HQ will continue to monitor the activities of the BCA anomaly investigation and evaluate schedules in planning for a new launch date and activities at the launch site. LSP will look at other launch opportunities for ICON in future.
If: The Pegasus launch vehicle Bolt Cutter Assembly (BCA) failure investigation options are not rendered before the end of April 2018; Then: NASA will inform Congress of a schedule breach.	The launch services program (LSP) at KSC, NASA Headquarters and the project will strategize scenarios based upon the options. NASA will prepare the breach notification as required. LSP will update launch availability and NASA will perform cost analysis and determine the launch plan after approach for modifying separation system is developed.

Acquisition Strategy

All acquisitions are in place. NASA selected ICON through the AO two-step process, and awarded the science investigation to the University of California Berkeley PI in April 2013.

MAJOR CONTRACTS/AWARDS

NASA awarded the mission Phase B through F (formulation through operations and closeout) procurement to the University of California at Berkeley for the PI-controlled mission. All major contracts are in place.

Element	Vendor	Location (of work performance)
FUV and EUV instruments	University of California, Berkeley	Berkeley, CA
MIGHTI instrument	Naval Research Laboratory	Washington, DC
IVM instrument	University of Texas, Dallas	Dallas, TX
Spacecraft, I&T	Orbital ATK	Dulles, VA
Payload integration	Space Dynamics Laboratory	Logan, UT
Launch Vehicle	KSC	KSC, FL

IONOSPHERIC CONNECTION EXPLORER (ICON)

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Jan 2014	SRR to evaluate ICON requirements	Successful	Jul 2014
Performance	SRB	Jul 2014	PDR to assess readiness for KDP-C	Successful	Apr 2015
Performance	SRB	Apr 2015	CDR	Successful	Aug 2016
Performance	SRB	Aug 2016	SIR to evaluate ICON readiness for KDP-D	Successful	Jan 2017
Performance	SRB	Jan 2017	Mission Pre-Environmental Review	Successful	Apr 2017
Performance	SRB	Apr 2017	ORR for KDP-E		Jul 2017
Performance	SRB	Jul 2017	Observatory Pre-Ship Review		2018
Performance	SRB	2018	KDP-E		2018

OTHER MISSIONS AND DATA ANALYSIS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Global-scale Observations of the Limb an	10.0	--	**7.7**	5.2	0.4	0.0	0.0
Ionospheric Connection Explorer (ICON)	39.4	19.0	**4.5**	1.3	0.0	0.0	0.0
Heliophysics Explorer Future Missions	6.0	--	**67.9**	224.6	173.7	175.5	69.4
Heliophysics Explorer Program Management	6.1	--	**5.0**	9.1	6.4	6.3	4.9
Interface Region Imaging Spectogr (IRIS)	7.7	--	**7.0**	6.5	6.5	6.5	5.9
Interstellar Boundary Explorer (IBEX)	3.4	--	**3.4**	3.4	3.4	3.4	3.1
TWINS	0.6	--	**0.6**	0.6	0.6	0.6	0.6
CINDI	0.3	--	**0.0**	0.0	0.0	0.0	0.0
Aeronomy of Ice in Mesophere (AIM)	3.0	--	**3.0**	3.0	3.0	3.0	2.7
Time History of Events and Macroscale In	5.4	--	**5.1**	4.5	4.5	4.5	4.1
ACE	3.0	--	**3.0**	3.0	3.0	3.0	2.7
RHESSI	1.9	--	**1.9**	1.9	1.4	1.4	1.1
Total Budget	**86.7**	--	**109.2**	**263.1**	**202.9**	**204.1**	**94.4**

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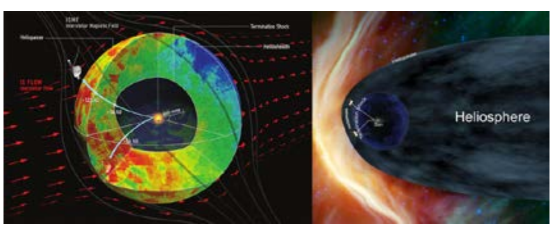


New data from NASA's Cassini, Voyager and Interstellar Boundary Explorer missions show that the heliosphere — the bubble of the Sun's magnetic influence that surrounds the inner solar system — may be much more compact and rounded than previously thought. The image on the left shows a compact model of the heliosphere, supported by this latest data, while the image on the right shows an alternate model with an extended tail. The main difference is the new model's lack of a trailing, comet-like tail on one side of the heliosphere. This tail is shown in the old model in light blue.

The Heliophysics Explorer Other Missions and Data Analysis budget includes operating Explorer missions, program management, and funding for future missions not yet approved as projects.

For more information, go to http://science.nasa.gov/about-us/smd-programs/explorers/.

Mission Planning and Other Projects

GLOBAL-SCALE OBSERVATIONS OF THE LIMB AND DISK (GOLD)

The GOLD investigation will perform unprecedented imaging of the Earth's thermosphere and ionosphere. For the first time,

OTHER MISSIONS AND DATA ANALYSIS

GOLD will answer fundamental scientific

questions about how the thermosphere/ionosphere system responds to geomagnetic storms, solar radiation, and upward propagating waves and tides.

Recent Achievements

The commercial satellite vendor successfully integrated GOLD with the spacecraft, and completed vibration and spacecraft acoustics. GOLD continues test and integration with the host spacecraft.

EXPLORER FUTURE MISSIONS

Explorer Future Missions provides the resources required to manage the planning, formulation, and implementation of all Explorer missions. The program office ensures successful achievement of Explorer program cost and schedule goals, while managing cross-project dependencies, risks, issues, and requirements as projects progress through formal key decision points. Additionally, Future Missions supports pre-formulation activities for missions not yet approved as projects.

EXPLORER PROGRAM MANAGEMENT

Explorer Program Management encompasses the program office resources required to manage Explorer projects. The program office is responsible for providing support and guidance to projects in resolving technical and programmatic issues and risks, for monitoring and reporting technical and programmatic progress of the projects and for achieving Explorer cost, schedule, and technical goals and requirements.

Recent Achievements

The Explorers program held the Heliophysics Small Explorers (SMEX) kick off meeting with the five Principal Investigator teams selected to participate in the Concept Study Review (CSR). The CSR is part of the step 2 process in mission selection for the 2016 Explorers AO.

Operating Missions

INTERFACE REGION IMAGING SPECTROGRAPH (IRIS)

IRIS is a SMEX mission selected in June 2009 and launched on June 27, 2013. IRIS joined a network of solar spacecraft and ground-based observatories to provide unprecedented insight into a little understood region of the Sun called the interface region. IRIS is enabling scientists to understand what energizes the solar atmosphere, providing significant new information to increase our understanding of energy transport into the corona and solar wind, which provides a model for all stellar atmospheres. The mission will extend the scientific output of existing heliophysics spacecraft that follow the effects of energy release processes from the Sun to Earth. IRIS provides key insights into all these processes, and thereby advances our understanding of the solar drivers of space weather from the corona to the far heliosphere by combining high-resolution imaging and spectroscopy for the entire chromosphere and adjacent regions.

Recent Achievements

Most research has gone into investigating how magnetic topology on the Sun creates favorable conditions for eruptions. However, on September 30, 2014, multiple NASA observatories (SDO, IRIS, Hinode and the VAULT2.0 sounding rocket), viewing in dozens of different wavelengths, watched as a filament rose from the surface, gaining energy and speed. Instead of erupting from the Sun as expected, the filament weakened and collapsed. To investigate, researchers developed a model that located strongly compressed and distorted regions of magnetic field lines where they expect rapid energy releases to occur. Typically, when solar structures with opposite magnetic orientations collide, they explosively release magnetic energy, heating the atmosphere with a flare and erupting into space as a coronal mass ejection - a massive cloud of solar material and magnetic fields. However, on the day of the September 2014 near-eruption, the model indicated the filament instead pushed up against a complex magnetic structure, shaped like two igloos smashed against each other. This invisible boundary, called a hyperbolic flux tube, was the result of a collision of two bipolar regions on the sun's surface. Evidence suggest that the hyperbolic flux tube broke the filament's magnetic field lines reconnecting them with those of the ambient Sun, so that the filament's magnetic energy was stripped away, effectively preventing the eruption from proceeding.

INTERSTELLAR BOUNDARY EXPLORER (IBEX)

IBEX is the first mission designed to image the edge of the solar system. As the solar wind from the Sun flows out beyond Neptune, it collides with the material between the stars, forming several boundaries. These interactions create energetic neutral atoms, particles with no charge that move very quickly. This region emits no light that conventional telescopes can see, so IBEX measures the particles that happen to be traveling inward from the boundary instead. IBEX contains two detectors designed to collect and measure energetic neutral atoms, providing data about the mass, direction of origin, and energy of these particles. From these data, researchers create maps of the boundary. The mission's focused science objective is to discover the nature of the interactions between the solar wind and the interstellar medium at the edge of the solar system. This region is important because it shields a large percentage of harmful galactic cosmic rays from Earth and the inner solar system.

Recent Achievements

The IBEX mission, launched in 2008, is the first spacecraft designed to collect data across the entire sky about the heliosphere and the solar system's boundary with interstellar space. A recent analysis of IBEX data has shown how the heliosphere "reacts" to variations in the polar coronal holes, which change in size with the 11-year solar cycle. The high-latitude polar coronal holes are the source of fast solar wind, while low latitude regions produce slow solar wind. A study by a team of scientists led by Dr. Eric Zirnstein of Princeton University analyzed IBEX observations of Energetic Neutral Atoms (ENAs) collected between 2009 and 2015 over a range of energies (speeds of ~350 to 900 km/s). The team was able to track the Sun's polar winds as they traveled out to the outer heliosphere where they interacted with hydrogen atoms, creating ENAs speeding back towards the Sun. Analysis of IBEX data reveals that it takes the solar wind near the Sun two to three years to travel to the heliosphere and then back toward the Sun to be seen as ENAs. In turn, the extent of the polar heliosphere expands and shrinks with changes at the Sun. These findings are generally consistent with Voyager observations.

TWO WIDE-ANGLE IMAGING NEUTRAL ATOM SPECTROMETERS (TWINS)

TWINS provides stereo imaging of Earth's magnetosphere, the region surrounding the planet controlled by its magnetic field that contains the Van Allen radiation belts and other energetic charged particles. TWINS gives a three-dimensional global visualization of this region, which has led to a greatly enhanced understanding of the connections between different regions of the magnetosphere and their relation to solar variability. TWINS is a NASA-sponsored mission of opportunity that has been operational since 2008 and currently in extended operations.

Recent Achievements

TWINS have obtained new observations, which have provided a more systematic and expanded understanding of storm phases and geomagnetic activities. These observations show these phenomena are partly dependent on the overall population of different ions found in the magnetosphere. Scientists can trace the time between when we detect these storms in the low altitude emission region, versus the ring current emission region, by following the transport of singly ionized oxygen (O+). It also appears to be dependent on the solar cycle.

AERONOMY OF ICE IN THE MESOSPHERE (AIM)

AIM is a mission to determine why polar mesospheric clouds form, and why they vary. Polar mesospheric clouds, Earth's highest-altitude clouds, form each summer in the coldest part of the atmosphere about 50 miles above the polar regions. These clouds are of particular interest, as the number of clouds in the middle atmosphere, or mesosphere, over Earth's poles has been increasing over recent years, possibly related to climate change. The spacecraft launched on April 25, 2007, completed its prime mission in FY 2009, and is currently in extended phase.

Recent Achievements

Scientists used AIM satellite data to categorize the inter-annual variability of winter and springtime upper stratospheric methane (CH4). They showed the effects of this variability on the chemistry of the upper stratosphere throughout the following summer. Years with strong wintertime mesospheric descent followed by dynamically quiet springs, such as 2009, lead to the lowest summertime CH4. Years such as 2011, with relatively weak wintertime descent but strong springtime planetary wave activity, have the highest summertime CH4. Since 2015, AIM has been observing the effects of gravity waves entering the Earth's mesosphere. Such observations have been key to understanding the global dynamic coupling between the Earth's atmosphere and its geospace environment.

OTHER MISSIONS AND DATA ANALYSIS

TIME HISTORY OF EVENTS AND MACROSCALE INTERACTIONS DURING SUBSTORMS (THEMIS)

THEMIS is a MIDEX mission that launched on February 17, 2007, and is currently in extended operations. Starting as a five-spacecraft mission, the three inner probes of THEMIS now focus on collecting data related to the onset and evolution of magnetospheric substorms, while the two outer probes (now referred to as ARTEMIS) have been repositioned into lunar orbits. Magnetospheric substorms are the explosive release of stored energy within the near-Earth space environment that can lead to space weather effects. The two ARTEMIS probes orbit the Moon's surface at approximately 100 miles altitude and provide new information about the Moon's internal structure and its atmosphere. ARTEMIS provides two-point observations essential to characterizing the Moon's plasma environment and hazardous lunar radiation. THEMIS and ARTEMIS, among others in the Heliophysics portfolio, are examples of missions offering important dynamics knowledge useful for future human spaceflight.

Recent Achievements

Scientists used Kelvin-Helmholtz (KH) simulations, motivated by THEMIS observations. The study finds that small fluctuations in the solar wind as it streams toward the Earth's magnetic shield can affect the speed and strength of these KH waves. The KH waves grow faster and stronger when solar wind fluctuations are stronger, under otherwise similar average conditions. Gaining deeper insights into how solar wind conditions affect space hurricanes may someday provide better space-weather prediction and set the stage for safer satellite navigation through radiation belts. This is because solar wind can excite ultra-low frequency (ULF) waves by triggering KH instability, which can energize radiation belt particles. Space hurricanes are universal phenomena, occurring at the boundary layers of coronal mass ejections – giant balls of plasma erupting from the Sun's hot atmosphere – in the magnetospheres of Jupiter, Saturn and other planets.

ADVANCED COMPOSITION EXPLORER (ACE)

ACE observes particles of solar, interplanetary, interstellar, and galactic origins as they pass by its location near the L1 Lagrangian point, located about a million miles from Earth toward the Sun. Changing conditions over the solar cycle are presenting new opportunities, including providing new insights relevant to space weather events.

Recent Achievements

In a recent paper researchers used ACE solar-wind flow-vector measurements and the properties of the ACE, Wind, and DSCOVR L1 orbits to estimate how well measurements of an upstream solar-wind monitor represent solar-wind properties hitting the Earth. This study shows that using a single spacecraft to study solar-wind driving of the magnetosphere system will not obtain the highest correlations, and that simulations of the reaction of the system to solar wind driving will not be the most accurate. Researchers suggested additional study could determine the optimum number of spacecraft in orbit about L1 to provide needed improvements in forecasting, or consider placing solar wind monitors closer to Earth.

RAMATY HIGH ENERGY SOLAR SPECTROSCOPIC IMAGER (RHESSI)

The RHESSI satellite focuses on the highest energy X-rays and gamma rays produced by the Sun, helping to observe solar flares of all shapes and sizes.

Recent Achievements

Radio observations are an ideal complement to RHESSI hard X-ray flare observations since they provide physically distinct perspectives on energetic electrons, hot plasma, and the magnetic field. Combining X-ray and radio observations at different wavelengths leads to important new diagnostics. RHESSI celebrated its 15th anniversary on February 5, 2017. It continues to be the only active observatory that can provide imaging spectroscopy of the energetic electrons that carry such a predominant part of the energy released in a flare.

RHESSI has now covered more than a complete 11-year solar cycle, and it is continuing to observe as activity decreases to solar minimum (expected sometime in 2019). During that time, it has recorded over 114,000 X-ray events, 42 with gamma-ray emission above 300 keV, and 27 with gamma-ray line emission.

AERONAUTICS

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	FY 2020	Notional FY 2021	FY 2022	FY 2023
Airspace Operations and Safety Program	140.6	--	**90.8**	96.2	120.4	122.7	122.9
Advanced Air Vehicles Program	274.6	--	**230.6**	248.5	257.1	257.8	258.3
Integrated Aviation Systems Program	125.0	--	**189.2**	154.1	106.6	103.3	102.5
Transformative Aero Concepts Program	115.8	--	**123.3**	110.1	124.9	125.1	125.1
Total Budget	**656.0**	**655.5**	**633.9**	**608.9**	**608.9**	**608.9**	**608.9**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

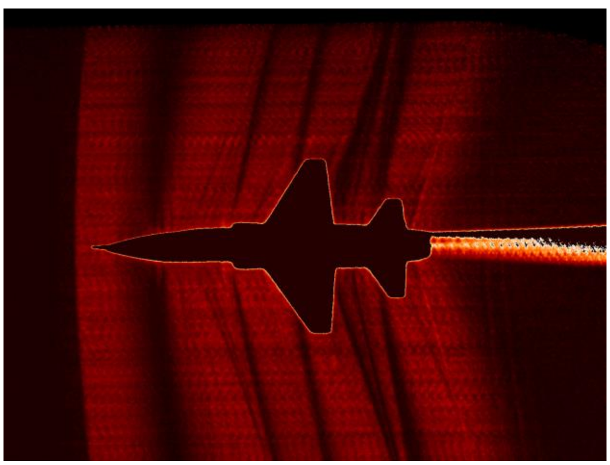
AERONAUTICS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Airspace Operations and Safety Program	140.6	--	**90.8**	96.2	120.4	122.7	122.9
Advanced Air Vehicles Program	274.6	--	**230.6**	248.5	257.1	257.8	258.3
Integrated Aviation Systems Program	125.0	--	**189.2**	154.1	106.6	103.3	102.5
Transformative Aero Concepts Program	115.8	--	**123.3**	110.1	124.9	125.1	125.1
Total Budget	**656.0**	**655.5**	**633.9**	**608.9**	**608.9**	**608.9**	**608.9**
Change from FY 2018			**-21.6**				
Percentage change from FY 2018			**-3.3%**				

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



NASA used an Air Force Test Pilot School T-38 and schlieren photography to capture shockwaves formed as the aircraft transitioned to supersonic speed. The technique will be used for future low-boom supersonic flight demonstrator flights.

An efficient and effective transportation system is fundamental to the future of the U.S. economy. Aviation is a highly visible and forward-looking component of transportation. Aviation moves the world, and the U.S. is a global leader in aviation technology.

Aviation accounts for more than $1.6 trillion annually of total U.S. economic activity[1] and is one of the few industries that generates a positive trade balance: $90 billion in 2016 alone.[2] The aviation industry supports more than 10.6 million direct and indirect jobs, including more than one million high-quality manufacturing jobs.[1]

NASA has had a highly productive research partnership with the U.S. aviation industry and the nation's foremost universities that has lasted for decades. This partnership has led to breakthroughs that have improved the efficiency, performance, and safety of aviation for all citizens. For example, the FY 2015 completion of the Environmentally Responsible Aviation (ERA) project

1 *"The Economic Impact of Civil Aviation on the U.S. Economy," FAA November 2016*

2 *"Leading Indicators for the U.S. Aerospace Industry." ITA, March 3, 2017*

demonstrated the potential impact of NASA Aeronautics research. Estimates for potential fuel savings through the application of ERA technologies through 2050 could approach 80 billion gallons.

Today, we stand on the cusp of the next era in aviation. Recent technology advances are coming together to enable breakthroughs in the speed and efficiency of the transport aircraft that are the backbone of the aviation system. Other breakthroughs will enable new markets for smaller aircraft, from unmanned aircraft systems (UAS) that serve search and rescue, agriculture, and commerce applications to the potential for new modes of personal transport. These innovations will support new jobs, new opportunities, and new ways for the U.S. to lead the world in technology and innovation.

To ensure research focus on enabling the next era in aviation, NASA's Aeronautics Research Mission Directorate (ARMD) guides its efforts with its visionary strategic implementation plan: http://www.aeronautics.nasa.gov/strategic-plan.htm. The plan lays out NASA's approach to addressing growing demand for global air mobility, the major challenges of energy efficiency and environmental sustainability, and the opportunity for convergence between traditional aeronautical disciplines and technology advances in information, communications, energy and other rapidly evolving technologies. The strategic implementation plan (SIP) identifies six research thrusts:

- Thrust 1: Safe, efficient growth in global operations.
- Thrust 2: Innovation in commercial supersonic aircraft.
- Thrust 3: Ultra-efficient commercial vehicles.
- Thrust 4: Transition to alternative propulsion and energy.
- Thrust 5: Real-time, system-wide safety assurance.
- Thrust 6: Assured autonomy for aviation transformation.

NASA's investment strategy follows long-term research roadmaps in order to enable major outcomes in each of these thrusts. The roadmaps are implemented in partnership with the aviation community and reflect solutions to aviation system needs that will provide benefits in mobility, environmental sustainability, and safety, while ensuring continued long-term U.S. aviation technology leadership in this rapidly expanding global industry.

The Budget fully supports NASA's new X-plane, the Low Boom Flight Demonstrator (LBFD), which will demonstrate quiet overland supersonic flight and open a new market to U.S. industry. In FY 2018, NASA will award a competitive contract for the detailed aircraft design, build, and validation of this X-Plane. The LBFD X-Plane is expected to achieve first flight by FY 2021. Initial flight activities will be focused on the safe expansion of the LBFD's flight envelope, but NASA will then proceed to conduct a sonic boom noise testing flight campaign. This campaign will generate data that will validate models used to design future airplanes with quiet supersonic features while also giving regulatory authorities a basis on which to set new supersonic noise regulations.

The Budget also increases funding for research on hypersonic flight by $5 million, which is critical to understanding how crewed and robotic spacecraft can safely enter and exit the atmospheres of planets. Hypersonics also has applications for national defense.

NASA has made significant advances in subsonic technologies that radically reduce fuel consumption, noise, and emissions. Among the key technologies are high aspect ratio wing, boundary layer ingestion engines, new aircraft configurations, and electric propulsion. NASA will develop these enabling technologies through physics-based simulations, ground test, and flight tests.

AERONAUTICS

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

Thrust 1: Safe, efficient growth in global operations

NASA successfully completed ATM Technology Demonstration 1 (ATD-1), also known as Interval Management - Terminal Area Precision Scheduling and Spacing. ATD-1 technologies will directly address airport terminal area congestion, by delivering the benefits of advanced flight arrival management technologies during moderate to high levels of traffic demand. The development of ATD-1 flight-deck interval management technologies culminated in a flight test in Washington State in February 2017. NASA installed and evaluated prototype flight hardware and software that allows pilots to manage the merging of their aircraft into the airport arrival stream and maintain safe spacing. ATD-1 closeout activities occurred in late FY 2017 after successful integration of the systems in the demonstration, final analysis, documentation, and technology transfer to the FAA. In September 2017, the ATD-1 software, known as Terminal Sequencing and Spacing for Air Traffic Control, was named NASA's 2017 Software of the Year.

NASA successfully completed preparations for an ATD-2 Phase 1 Departure Metering demonstration at the Charlotte Douglas International Airport, the test site for this initial simulation of a new departure metering capability. This demonstration supported the FAA’s joint government/industry initiative aimed at improving air traffic flow management through increased information exchange among airline and airport stakeholders. The ATD-2 team and field demonstration partners have completed several additional shadow sessions, a major integrated human-in-the-loop (HITL) simulation, Phase 1 requirements evaluation, and risk management review. These activities enabled an affirmative systems readiness decision to allow commencement of the Phase 1 demonstration in late September 2017 through fourth quarter FY 2018.

Thrust 2: Innovation in commercial supersonic aircraft

NASA reached a major milestone for commercial supersonic aircraft by developing "Intermediate Tools for Sonic Boom Community Reponses" which represents a key step for enhancing computational tools to aid in understanding the impact of noise from sonic booms. With these tools, NASA has created a foundation of innovative concepts that will enable future airport noise regulations to be met while enabling industry to demonstrate overland supersonic flight with acceptable sonic boom noise in the future. Data are necessary for supporting a change for regulation, but these tools are needed to help ensure that the best data are obtained and also to determine how to project the effects to a wider variety of locations because it would not be possible to actually fly a low boom aircraft over every community. Ultimately, this research will assist in the ability to establish a new low boom regulation that opens the door to a commercial supersonic transport market.

In addition to developing computational tools, NASA made significant progress during FY 2017 on the LBFD project. In FY 2017, NASA successfully completed the preliminary design for the LBFD test aircraft. This effort addressed integration of all aspects of a design that enables the mission requirements of the LBFD to be met. Scaled models of the design were tested in the NASA Glenn Research Center wind tunnels in 2017 to validate the performance against the project requirements.

Thrust 3: Ultra-efficient commercial vehicles

NASA conducted research aimed at developing future aircraft that could dramatically reduce fuel burn, noise, and emissions substantially below current limits. At NASA's Glenn Research Center 8' x 6' wind tunnel, NASA completed the installation of a Boundary Layer Ingestion (BLI) System which will enable radical reductions in fuel burn and noise reductions for future generations of aircraft, primarily by reducing the amount of drag created by conventionally mounted engines. This new capability was successfully used during a collaborative effort between NASA and United Technologies Research Center to conduct a transonic wind tunnel test of a new gas turbine engine fan design that could withstand the distorted air inflow due to BLI with minimal effect on fan performance and stability. These experiments assisted in the quantification of the BLI impact on fan performance and structural characteristics at cruise conditions. Ultimately, BLI technology could provide a significant improvement in the efficiency of future aircraft.

NASA collaborated with Aurora Flight Sciences to validate operational benefits and identify integration challenges associated with a new fuel-efficient aircraft configuration that incorporates BLI for reduced airframe drag. This validation was done by completing a Conceptual Design Review of the aircraft configuration and a Preliminary Design Review of the aircraft structure. These reviews helped NASA and Aurora to understand the feasibility and risks associated with how well this new aircraft concept will perform as well as how to potentially integrate BLI technology on future unconventional configurations.

NASA completed Phase I tasks in the Advanced Composites Project, which focused on reducing the time and/or cost of implementing new composites structures in future air vehicle designs. A key aspect of the completed Phase I work was the assessment and initial development of computational tools that would accurately predict the strength and life of composite designs. In addition, NASA also advanced key technologies to rapidly test and inspect composite structures for possible damage. The Advanced Composites Project is scheduled to conclude in FY 2019.

NASA conducted flight tests of the aerodynamics of a wing with an adaptive compliant trailing edge (ACTE) and a new landing gear fairing concept designed to reduce noise. To date, the flight tests have verified improved wing aerodynamics with the ACTE flap installed, and significant acoustic benefits through the use of landing gear noise reduction fairings; in addition, flight tests have enabled acoustic tool validation that will be instrumental in developing landing gear noise reduction treatments for future aircraft. ACTE testing will continue into early FY 2018, and additional testing of the landing gear noise reduction fairing concept and tool validation will continue into late FY 2018.

NASA, in partnership with the U.S. Army and Penn State University, has successfully designed, patented and fabricated two innovative two-speed transmission systems for vertical lift vehicles, the Dual-Star Idler and the Offset Compound Gear, including the development of a unique test facility for scaled transmission configurations for these vehicles. This new technology enables a turbine engine to continue to operate efficiently even while its internal speed is slowed down. NASA has also developed and patented new hybrid metal/composite gears to reduce transmission system weight compared to the current all-metal systems. The ability to slow a rotor provides a long sought-after capability for vertical lift vehicles that allows significant improvements in performance and reduction of noise. The reduction in weight resulting from the use of lightweight hybrid component technologies could be applied beyond vertical lift to other aviation vehicles and the automotive industry.

Thrust 4: Transition to alternative propulsion and energy

NASA worked with airframe and engine manufacturers as well as universities to identify and analyze propulsion and power system options for next generation aircraft. These analyses verified the benefits of the new propulsion systems for a single aisle class of transport airplane and will be used to guide the technology development efforts on specific components. For example, turboelectric and hybrid electric designs are showing promising energy reductions of up to 15 percent for the propulsion system alone, which can also be augmented by improvements in other technologies, such as materials and wing design.

NASA brought online the NASA Electric Aircraft Testbed (NEAT) to support its first powertrain testing of subscale (kilowatt) aircraft systems. The NEAT facility enables powertrain research and technology development for electric aircraft systems at power levels relevant to a full-scale, single-aisle aircraft. The testbed successfully passed safety reviews and tests were completed at the 125 kilowatt and 250 kilowatt power levels. These tests validated and matured the strategies required for using electric machine pairs to emulate the coupling between a turbine engine and an integrated electrical generator, and an electric motor driving a propulsive fan. These strategies are the key building blocks for electrified aircraft powertrains that will be tested over the next several years while increasing power, voltage levels, and architectural complexity, eventually leading up to full-scale (megawatt) systems.

NASA, along with its partner Boeing, made substantial progress in advancing technologies aimed at hybrid electric propulsion for large commercial aircraft. In FY 2017 system-level assessments of several promising hybrid electric/turboelectric concepts, such as those that utilize a turbine engine that not only provides thrust, but also generates electricity that can be used to turn fans located in different parts of the aircraft. Such configurations offer a possibility for increased efficiency that is not possible with traditional configurations that we see today. All configurations that were assessed showed significant reductions in fuel burn compared to conventional aircraft. In addition to the system-level assessments, NASA designed high-efficiency and high specific power megawatt-scale powertrain components such as the electric motors/generators and power converters.

In addition to the design and advancement of components to enable all-electric or hybrid gas-electric propulsion systems, NASA investigated small-core combustion engine technologies. The collective effect of this research is the potential for low or nearly no carbon emission propulsion advancements. In the area of advanced combustors, NASA and United Technologies Research Center completed initial single-sector concepts for the 2035 timeframe focusing on lowering emissions, fuel flexibility, and advancing small core combustor architectures that reduce landing and take-off nitrogen oxides by 80 percent below the standards set by the International Civil Aviation Organization and its committee on Aviation Environmental Protection in 2010.

NASA continued the development of the X-57 Maxwell aircraft, a general aviation-scale aircraft to test highly integrated distributed electric propulsion technology. This demonstration is an important first step toward assessing the benefits and challenges of operating more electrified aircraft. The X-57 effort is being conducted in multiple phases called “Mods.” For Mod II, the gas-powered engines of the aircraft will be replaced by electric cruise motors. For Mod III, the wing will be replaced with a newly-designed high aspect ratio wing, and the electric cruise motors will be installed on the wing tips. And for Mod IV, an array of smaller electric propulsors will be installed along the wing leading edge to demonstrate the effectiveness of Distributed Electric Propulsion. Beyond demonstrating the increased efficiency and feasibility of electric propulsion technologies, the single most important achievement for the X-57 effort will be the learning associated with successfully integrating electrified propulsion, and the highly complex supporting systems, into an aircraft. This learning will be broadly shared with the aviation community to advance U.S. readiness for application of electric propulsion technology.

Thrust 5: Real-time, system-wide safety assurance

NASA sponsored a study on real-time safety conducted by a committee convened by the National Academies of Sciences, Engineering, and Medicine. The committee is developing recommendations for a national research agenda to develop in-time capabilities to detect, predict, and prevent safety problems in the National Airspace System. The report was delivered in January 2018.

NASA continued to develop and transfer tools and methods to assure safety in complex aviation systems and data. At the request of the Radio Technical Commission for Aeronautics (RTCA), NASA identified and solved a problem with an algorithm in the world's automatic dependent surveillance-broadcast specification and provided multiple solutions to permanently remedy the error. Researchers developed and demonstrated a framework that verifies streaming FAA System-Wide Information Management aviation data feeds. NASA also delivered a Verification and Validation (V&V) Toolbox to the FAA Technical Center. The NASA developed tools provide automated assurance of the code underlying air traffic management systems. Tools to verify systems at the design level will be added to the FAA Technical Center toolbox in FY 2018. All tools are open source and available to system developers in industry as well as at the FAA.

In addition, NASA continued progress on research to evaluate causes of loss of energy state and/or attitude state awareness in support of the Commercial Aviation Safety Team's (CAST's) Safety Enhancements. Activities included validating scenarios for attention-related performance limitations, maturing avionics display concepts and technologies and development of Augmented Flight Deck Countermeasures – work that was highlighted in briefings to the RTCA. NASA completed the Stall Recovery Guidance simulator study, which investigated pilots' failure to recognize conditions leading to aerodynamic stall and limitations in their ability to respond appropriately to an unexpected stall or upset event.

Thrust 6: Assured autonomy for aviation transformation

NASA developed, matured, and tested the second technical capability level (TCL2) for UAS traffic management (UTM) for small UAS operating at low altitudes which incorporated weather/wind integration, trajectory routing, object avoidance, and congestion management at an initial flight trial at Nevada's Reno-Stead Airport. The initial flight trial was followed-up with TCL2 distributed tests (National Campaigns) using selected FAA UAS Test Sites across the United States. TCL2 technology was an integral part of the completed National Campaign 2 where six geographically diverse UAS Test Sites flew multiple pilot operations beyond visual line of site in lightly populated rural environments (May 2017 to June 2017). Researchers tested technologies that allowed dynamic adjustments to user-requested flight plans based on availability of airspace and contingency management. The TCL2 flight validation connected real drone-tracking systems to the UTM research platform, providing alerts for approaching drones and piloted aircraft (live or simulated), as well as providing information about weather and other hazards. NASA delivered the results from TCL2 flight test to the Unmanned Aircraft Safety Team, the FAA Research Transition Team, the Science and Research Panel, and the Association for Unmanned Vehicle Systems International. A NASA Technical Memorandum describing the demonstration of necessary data exchange between the UTM TCL2 components was included in the technology transfer to the FAA in April 2017.

NASA's UAS Integration in the NAS (UAS-NAS) project closed out Phase 1 in parallel with the execution of Phase 2. The UAS-NAS Phase 1 effort informed the development of Phase 1 Detect and Avoid Minimum Operational Performance Standards (MOPS) for large UAS transiting through Class E Airspace to high altitude enroute airspace (Class A) for RTCA's Special Committee on UAS Integration into the NAS (SC 228) Special Committee 228. The project is working in conjunction with RTCA in developing standards necessary for UAS operations in the NAS. This MOPS will enable the FAA to develop Technical Standard Orders so that Industry can build UAS flight hardware capable of safely integrating into the NAS.

NASA, in cooperation with the FAA, began planning to obtain a No Chase Certificate of Waiver or Authorization (NCC) for a UAS flight demonstration. The planned FY 2018 demonstration will be the first-ever flight of a UAS in the NAS without a safety chase aircraft to enable a pilot to "see and avoid" other aircraft. The purpose of the demonstration is to fly a UAS in multiple Classes of airspace in order to demonstrate the feasibility of integrating the Phase 1 Detect and Avoid (DAA) technologies as an alternate means of compliance with the current rule for pilots to "see and avoid" aircraft.

Cross-Cutting Capabilities

NASA completed a diverse set of hardware modifications in the Ames Unitary Plan Wind Tunnel creating an "Optical Test Section of Tomorrow." For this transonic/supersonic wind tunnel, modifications were made to upgrade the data acquisition system for test model surface pressures and off-body aerodynamic measurements, and also increase productivity and data accuracy through advanced optical instrumentation and techniques. This new capability will allow researchers to accurately and efficiently identify and understand the complex flow phenomena of next generation aircraft and space vehicles in realistic flight conditions.

NASA improved the accuracy of critical turbulence models and numerical methods for separated flows by reducing the predictive error by 40 percent against standard test cases. Current fluid models have been unreliable in representing turbulent flow regions including separated flows. These limitations have prevented the broader use of numerical modeling for aircraft design, leading to higher costs and less than optimal designs. NASA's turbulence models are one key contribution to the CFD 2030 Vision, a collaborative effort recently established by leading fluid dynamics experts from government, industry, and academia.

NASA demonstrated a high-temperature material system for turbine engine components that enable a 6 percent reduction in fuel burn while meeting 2700 F use temperature and durability metrics. Higher temperature materials reduce the amount of cooling needed in engine turbines, improve fuel efficiency, lower operating cost, and reduce emissions. As part of this effort, NASA has been collaborating with a U.S. engine company to advance these high-temperature ceramic matrix composites (CMC) materials. The company plans to incorporate CMCs into the hot section of a new engine that will power the next generation of commercial airplanes.

NASA completed feasibility assessments for four Convergent Aeronautics Solutions (CAS) activities. These studies culminated the initial exploration of innovative new aeronautics concepts and contributed knowledge and technology advancements across several areas. Contributions include a new toolset for designers of small unmanned aerial vehicles and a concept that uses robotic construction of aircraft structures using strong, lightweight materials; another concept can significantly reduce ground testing time by allowing a new aircraft to "learn" its control system in flight similar to how a young bird learns to fly by jumping out of the nest. NASA is discussing a potential technology transition of this concept to a

U.S. aerospace company. The final CAS activity demonstrated a concept that uses advanced sensors and models to create a "digital twin" that can predict the performance of a physical system over its lifecycle. NASA will use all results from the assessments to guide future investments and to provide essential knowledge that can benefit other ARMD programs and the aviation community.

NASA executed the first round of the competitive University Leadership Initiative awards under the University Innovation (UI) Project with five awards. These awards are the result of university leaders independently identifying technical barriers inherent in achieving ARMD's strategic outcomes, and proposing multi-disciplinary solutions to address those barriers. Total participants for all awards include twenty-one universities, seven companies, and one non-profit organization across twenty-one states.

Hypersonic Capabilities

In FY 2017, NASA started the Hypersonic Technology Project to develop synergistic technology and knowledge that benefit NASA's long-term interests for commercial applications while leveraging Department of Defense interests. During the year, NASA completed an assessment of approaches to better estimate the uncertainty of models and designs of hypersonic systems. These approaches will be applied to computer models and validated with ground test and flight data. Ultimately, this will lead the way to new design tools that facilitate the development of a variety of hypersonic vehicles. Additionally, NASA conducted tests that improved the project's understanding of how to develop a high-speed propulsion system that can take off like a traditional jet airplane and transition to a scram jet for increased speed. NASA is researching how to optimally make this transition and is developing tools and guidance that others can eventually use to design reusable hypersonic vehicles.

WORK IN PROGRESS IN FY 2018

Thrust 1: Safe, efficient growth in global operations

NASA has begun operational evaluation and demonstration of ATD-2 technologies that improve sharing of operational information to better plan and schedule aircraft movement. The ATD-2 computer-driven scheduling tools will help traffic managers coordinate flight schedules at the ramp, tower, terminal and center control facilities, and make better decisions about how to reduce congestion during the busiest times at airports and improve departure times saving fuel, time, and money. ATD-2 operational evaluations and demonstration will be conducted in three phases: Phase 1 will demonstrate a baseline integrated arrival, departure and surface system, to include the FAA's Surface Collaborative Decision Making concept, at CLT in Charlotte, NC and the FAA Air Traffic Control Center in Washington, DC and in FY 2020 phases 2 and 3 including a field demonstration with participation of NASA and FAA Air Traffic Control Centers in Charlotte, NC; Washington, DC; and Atlanta, GA in FY 2020.

Thrust 2: Innovation in commercial supersonic aircraft

While significant progress has been made in developing noise prediction tools, there is still more work needed to provide the comprehensive understanding that the rule making community will need to actually change regulations. NASA is continuing development of additional models for the prediction of the community response to noise created by the overflight of future supersonic commercial aircraft. Based on simulations conducted in NASA's Interior Effects Laboratory, the first of these models will be capable of predicting the response of a person who hears supersonic overflight noise while indoors. The second of these models will be used to predict the indoor noise created by supersonic overflight in a wide variety of homes with different room arrangements and construction techniques. With the combination of these models, NASA will perform analytical studies of community responses to the overflight noise of future supersonic commercial aircraft, which will provide the underlying data needed for NASA to develop future community overflight experiments.

NASA will award a contract for the LBFD flight demonstrator aircraft to perform detailed design, build, test, and flight validation. This demonstrator will be used to collect the flight and community response data necessary to establish overland supersonic noise regulations. In addition, NASA will conduct the KDP-C for the LBFD aircraft. The successful completion of KDP-C will represent Authorization to Proceed to the execution phase of the project with validated plans for the cost and schedule of the LBFD project.

Thrust 3: Ultra-efficient commercial vehicles

NASA will build upon the significant advances in recent years for new ideas and concepts for designing much more efficient aircraft and further explore some of the most promising technologies to ensure that they can be used by industry for future products. For example, NASA is continuing to investigate the potential benefits of the integrated Boundary Layer Ingestion technology for engines that can be mounted and partially embedded, on top of an airframe in a way that is much more efficient than traditional under-the-wing engine configurations. Recent boundary layer ingestion test results show an overall vehicle efficiency benefit, but another key factor in determining if this concept is viable is to determine if an engine’s fan can be designed to handle the uneven air flow resulting from this configuration. The newly installed Boundary Layer Ingestion system at NASA Glenn will continue to be utilized to better understand how to design future fans for such a configuration. If successful, this work will lay the path for new designs that offer significant aircraft performance benefits.

NASA is focusing on reducing community noise through the Landing Gear Noise Reduction (LGNR) effort to demonstrate novel landing gear porous fairing and wheel cavity treatments. Flight testing is planned during spring 2018. In addition, the LGNR effort will extend the simulation-based airframe noise prediction methodology to the undercarriage and high-lift systems of large civil transports. The goal is to reduce the airframe component of community noise by 1.5 PLdB [Perceived Level (PL), decibels (dB)], or approximately 30 percent, with minimal impact on aircraft weight and performance, and to validate an advanced, physics-based methodology for the accurate prediction of airframe noise.

In order to help improve the performance, efficiency, and noise reduction for new higher-speed vertical lift configurations, NASA is demonstrating Multi-Fidelity Design Optimization processes for low-noise and low-emissions Vertical Take Off and Landing (VTOL) designs. The ability to use computational optimization processes will enable design engineers to efficiently assess and compare design and technology options to create advanced concepts for cleaner and quieter VTOL configurations. These advances will help pave the way for new vehicles that can be used for new missions such as economical inter-urban transport.

Thrust 4: Transition to alternative propulsion and energy

NASA will continue to partner with universities, industry, and other government agencies to investigate, develop, and test small-core, fuel-flexible combustor technologies that take full advantage of the attributes of alternative drop-in jet fuels. These advanced technologies have the potential to reduce nitrogen oxide emissions and particulate matter pollutants to 80 percent below the international standard with minimal impacts on weight, noise and component life. Additionally, these benefits will be compatible with both gas-turbine-only and hybrid-gas electric architectures.

NASA, in partnership with United Technologies Research Center, Pratt and Whitney, and Woodward, will continue studying newly designed small-core combustors in order to obtain landing and take-off nitrogen oxide emissions data at relevant engine operating conditions. In addition, NASA will continue to focus on establishing a viable concept for a 5-10 megawatt hybrid gas-electric propulsion system for commercial transport aircraft focusing on demonstrating an overall system-level energy usage reduction.

NASA will continue to advance propulsion concepts in the NEAT facility by preparing and testing a simplified subscale powertrain for NASA's 2.6 megawatt Single-aisle Turboelectric Aircraft with Aft Boundary Layer (STARC-ABL). STARC-ABL is a lightly distributed architecture where power is drawn from two under-wing turbine engines and transferred to the tail of the aircraft where an electric motor drives a propulsive fan. This concept provides additional thrust while reducing drag because of how it interacts with the air moving close to the aircraft body, known as the boundary layer. Tests currently underway are resolving controls, safety, and electromagnetic interference issues using non-flight weight components at 500 kilowatts and 600 Volts. Designs for a megawatt-scale powertrain with additional systems added for energy storage, fault isolation and dynamic controls will be completed in FY 2018 and plans are in place to install and demonstrate a MW- class powertrain in FY 2019.

NASA's X-57 project is conducting Mod II configuration flights. These flights represent a crucial step in the flight test process as the conventional fuel engines will be replaced with electric motors and electrical storage and power distribution systems needed for all-electric flight. Following Mod II flights, the X-57 aircraft will be modified to the Mod III configuration; this includes integrating the newly designed, high-aspect ratio wing on the aircraft, and integrating the electric cruise motors onto the wing tips. The Mod III high aspect ratio wing will be delivered in FY 2018. Cruise efficiency gains are anticipated for the X-57 during the Mod III flights planned for FY 2019.

Thrust 5: Real-time, system-wide safety assurance

NASA will transfer safety assessment tools and build on legacy system-wide safety work to make progress toward in-time monitoring and assessment capabilities. A validated human fatigue monitoring tool will become publicly available in the Apple App Store and NASA-developed anomaly detection code (currently in use by several airline partners) will be integrated into the FAA's Aviation Safety Information Analysis and Sharing (ASIAS) vulnerability database. NASA will also look to address future potential safety risks associated with emerging markets. Researchers will develop a baseline data monitoring functional design and requirements for selected safety risks associated with new entrants such as UAVs as well as a baseline capability simulation and/or flight tests to support in-time risk assessment and conformance-related monitoring.

NASA will continue to develop and evaluate tools and methods that support the ability to assure safety in aviation systems early in the development lifecycle. These improvements will reduce cost, as well as support industry use of these new verification and validation (V&V) methods by helping the FAA develop new paths to certification that employ evidence from these methods. NASA will deliver an automated tool that assures safe design of new systems to the FAA for inclusion in their NASA V&V toolbox. NASA will also continue development of automated solutions for assurance of automated systems by defining requirement categories for classes of autonomy algorithms involving learning and/or optimization, as well as developing tools to check systems for these requirements. In addition, NASA will determine whether there are means for automated safety assessment of non-deterministic systems either pre-deployment or in operation. A joint NASA/Air Force Research Laboratory symposium for V&V of autonomous systems will be held at NASA Ames Research Center in August 2018.

NASA will conclude most of the work in support of the CAST Safety Enhancement for airplane state awareness. A simulation will evaluate piloted models that support stall training requirements. NASA will also coordinate with the FAA and manufacturer research organizations to develop enhanced tools and methods to represent flight crew responses in situations associated with loss of energy state and/or attitude state awareness.

Thrust 6: Assured autonomy for aviation transformation

NASA will develop and demonstrate the third technical capability level (TCL3) for UTM focusing on the requirements to manage separation by vehicle and/or ground-based capabilities under higher densities. The focus areas will build upon research validated under TCL2 (demonstrating operations beyond the visual line-of-sight) over moderately populated land with some interaction with manned aircraft. In addition, vehicle tracking/internet connectivity will enable validation of requirements for active monitoring of trajectory conformance. This capability is relevant to public safety concerns (i.e., emergency and disaster response, fire management, HAZMAT, etc.) and commercial interests (i.e., package delivery, security, telecommunications, etc.).

NASA's UAS-NAS project will continue the development of Phase 2 Minimum Operational Performance Standards (MOPS) in support of the FAA. As a key part of this development, the project will continue to work with industry to develop an alternative airborne surveillance sensor system for mid-size UAS. The sensor will be designed to be low size, weight, and power due to the size constraints for a mid-size UAS. RTCA Special Committee 228 is the primary stakeholder to in developing MOPS for this airborne surveillance sensor. The sensor will undergo flight testing to validate the simulations.

Cross-Cutting Capabilities

NASA will complete the design and installation of a new acoustical treatment in the Glenn Research Center 9x15-Foot Low-Speed Wind Tunnel. This improvement will further reduce the facility's background noise to levels that will enable testing of next-generation low-noise propulsion system concepts.

NASA will continue working on computational tools that improve new air vehicle design such as Revolutionary Computational Aerosciences, Multidisciplinary Design, Analysis, and Optimization, and Combustion Modeling. These tools will evaluate key enabling technologies for future subsonic aircraft configurations, advanced gas turbine engines, and/or hybrid electric propulsion systems that will achieve revolutionary levels of economic and environmental performance.

NASA's CAS Project initiates three new activities that support the Urban Air Mobility (UAM) domain. The first activity, Autonomy Teaming and Trajectories for Complex Trusted Operational Reliability, will develop and measure trust inherent in autonomous systems. The second activity, Fit-2-Fly, will focus on conducting automated monitoring and inspection of UAVs. Finally, the third activity, Quantum Technologies for UAS, will apply quantum computing technologies to support secure UAV communications.

Hypersonic Capabilities

NASA will continue to coordinate closely with partners in the Department of Defense (DoD) to leverage their investments in flight activities that develop and validate advanced physics-based models, while at the same time the DoD leverages NASA expertise, analyses, testing capabilities and computational models. NASA will also conduct ground test experiments to advance the feasibility of future systems that could use a turbine engine at slow speeds and then transition to a scramjet for high-speed operations. In addition, NASA will perform fundamental research in the areas of high-speed propulsion, re-usable vehicle technologies, and high-temperature materials. Systems analysis will also be performed greatly increasing the flexibility and utility of high-speed vehicles.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

Thrust 1: Safe, efficient growth in global operations

NASA will conduct the ATD-2 Phase 2 operational demonstration to evaluate the fused Integrated Arrival/Departure/Surface (IADS) system capability. Phase 2 will demonstrate the benefits of strategic surface metering during periods of significant demand/capacity imbalance and enhance tactical surface metering to improve non-movement area predictability and throughput. The ATD-2 capability will be expanded to validate more scheduling scenarios for Washington and Atlanta Air Route Traffic Control Centers and will culminate in a Phase 3 full system Metroplex IADS demonstration in FY 2020.

Thrust 2: Innovation in commercial supersonic aircraft

NASA will complete a "Sonic Boom Community Response Metric and Methodology" technical challenge by validating field study methodology, including indoor and outdoor noise metrics, exposure estimates, survey tools, and test protocols to support community studies for a low-boom flight demonstration.

NASA will conduct a Critical Design Review (CDR) as the culminating event to final design activities for the LBFD aircraft. Following a successful CDR, the aircraft contractor will conduct aircraft build activities that include component fabrication and assembly, integration of government furnished equipment, and final systems checkout in anticipation of NASA conducting a Flight Readiness Review late in FY 2020.

Thrust 3: Ultra-efficient commercial vehicles

NASA will explore a concept of tailoring aircraft structures so that weight is minimized in areas where it is not needed. NASA will focus on completing three key technical challenges in the area of accurate strength and life prediction, rapid inspection and characterization, and efficient manufacturing process development to help demonstrate the viability of this concept. An important milestone will also be accomplished by demonstrating computer-based tools, methodologies and system-level assessments, which will reduce the time required to develop and certify composite structures.

NASA will continue Landing Gear Noise Reduction work on a simulation-based airframe noise prediction methodology for the undercarriage and high-lift systems of large civil transports. Through simulations, this effort plans to demonstrate approximately a 30 percent reduction in the airframe component of community noise with minimal impact on aircraft weight and performance. Planned work on this advanced physics-based methodology for the accurate prediction of airframe noise will be completed in FY 2019.

NASA will lay the foundation for establishing a new multi-disciplinary design capability that will benefit a wide variety of vertical lift vehicle sizes. This new design approach will enable industry to develop conceptual designs of advanced vertical lift vehicles while taking into account multiple disciplines and aspects of the configuration design. Additionally, a focus in FY 2019 will be to complete a technical challenge for demonstrating design and flight operation methods for reducing VTOL aircraft noise impact, while accomplishing a milestone for achieving noise reductions of at least five decibels (dB) on approach for VTOL tests designed for low noise.

NASA will complete the Advanced Composites project, which will deliver a variety of computational tools and guidance that will significantly reduce the time needed to develop and certify new composite structures for aerospace applications. Currently, this process is very time-consuming due to the significant testing that is needed. The goal of this project is not to eliminate testing, but rather supplement such testing more effectively with computational models that will allow industry to conduct more efficient tests, thus reducing the development time by up to 30 percent, which will also reduce the cost significantly. Among the computational tools being developed by NASA are those capable of modeling composite materials to better predict their strength and durability. NASA will advance the methods that are used to inspect structures to both ensure the models are accurate and to improve the quality of production. Finally, NASA will develop methods to better implement these tools and practices into the manufacturing process so that they can be used most effectively. This project utilizes a public-private partnership to ensure that NASA is closely coordinated with both the FAA and industry so that the results can be implemented quickly and effectively.

Thrust 4: Transition to alternative propulsion and energy

NASA will establish a viable concept for 5-10 megawatt hybrid gas-electric propulsion system required for commercial transport aircraft. A main focus area is in the superconducting motor component, which advances a key technology needed to realize practical larger-scale hybrid electric propulsion systems for the future. Further, in partnership with industry, NASA will advance a megawatt-scale non-superconducting inverter to a higher technical maturity level. This advancement complements the superconducting motor and increases the technology options available to hybrid electric propulsion system designers as they identify and develop larger ground and flight demonstration opportunities.

NASA's X-57 Maxwell will conduct flights in the Mod III configuration. These flights will be performed following the integration of the new, high-aspect ratio wing. In addition, the Mod III configuration, while still utilizing all-electric systems, will feature mounting electric motors for primary propulsion on the wing tips. As a result of these significant aircraft modifications, many of the integration challenges associated with installation of electrical and power distribution components will be addressed as the aircraft is prepared for flight.

Thrust 5: Real-time, system-wide safety assurance

NASA will provide an initial demonstration of in-time hazard identification by using a NASA-developed framework at the FAA to monitor and identify incident precursor patterns. Flight anomaly detection code will also undergo a final hand-off and be integrated into daily operations at the FAA's Aviation Safety Information Analysis and Sharing (ASIAS), a database of safety related data from across government and industry. In addition, NASA will develop a framework for representing and managing uncertainties in streaming aviation data.

NASA efforts in the area of V&V will include developing and delivering draft guidance for demonstrating confidence in safety claims based on a system's overarching properties, opening the way for an automated safety assurance process. NASA will also develop a safety assurance dashboard that can give a comprehensive view of retired and residual risks and will document a new Model-Based Safety Analysis approach for complex, safety-critical systems. NASA will continue to provide automated safety assurance methods for autonomous systems by developing foundations for mitigation of residual risk in autonomous algorithms and techniques for (semi-) automatic mitigation of numerical errors in safety-critical autonomous systems.

NASA will also complete the final deliverables to Commercial Aviation Safety Team. NASA will deliver formal reporting methods to reduce risk of loss-of-control accidents (SE-200, "Virtual Day-Visual Meteorological Conditions Display Systems") and an evaluation of display strategies to provide control guidance for recovery from approach-to-stall (SE-207, "Attitude, Energy State and Airplane Systems Awareness Technologies). Closeout activities for this effort will be complete by fourth quarter FY 2019.

Thrust 6: Assured autonomy for aviation transformation

NASA will develop and demonstrate the fourth and final technical capability level (TCL4) for UTM focusing on large-scale UAS operations in higher-density urban areas. The demonstration will also test technologies that could be used to manage large-scale contingencies (i.e., communication/navigation failures, disaster scenarios, etc.). These focus areas will build upon all research validated under TCL3 (managing safe spacing of vehicles and ground-based capabilities under higher densities) over densely populated land with some interaction with manned aircraft. In addition, autonomous vehicle-to-vehicle communications and internet connectivity will enable validation of requirements for active monitoring of trajectory conformance. This capability is relevant to commercial interests (i.e., news gathering, package delivery, security, telecommunications, etc.).

NASA's UAS-NAS project will complete flight testing of a low size, weight, and power airborne Detect and Avoid (DAA) surveillance capability. This flight demonstration is a key contributing event to Phase 2 DAA MOPS development in support of RTCA Special Committee 228 standards development for UAS. Also, the project will complete a flight test of a new control and non-payload communications radio in expected relevant operational environments. The test will demonstrate command and control capability in flight and contribute to Phase 2 standards development in support of RTCA Special Committee 228.

Cross-Cutting Capabilities

NASA will complete a series of new capabilities and test technologies for several wind tunnels. NASA's Propulsion Systems Laboratory will confirm its capability to simulate the high ice water content cloud conditions experienced in nature to the degree required to simulate the aviation safety issue of engine icing.

NASA will begin new CAS activities from incubation supporting multiple strategic thrusts. The following CAS activities will go to close-out/transition: Lithium-Oxygen battery for NASA; Spanwise Adaptive Wing; Fostering Ultra-Efficient, Low-Emitting Aviation Power; Compact Additively Manufactured Innovative Electric Motor; and Conformal Lightweight Antenna Systems for Aeronautical Communication Technologies.

Hypersonic Capabilities

NASA's work on creating better methods to predict the uncertainty of computational models for hypersonic systems will be put to practice on the first demonstrations to explore the effect on an overall system. This will provide needed information to more efficiently design future hypersonic vehicles and also help identify which components have the biggest impact on vehicle performance, which will help NASA focus other research to have more impact. The results of this work will be shared with U.S. partners and applied to both ground and flight testing in the future.

NASA will conduct a key experiment to demonstrate an autonomous mode transition in a turbine-based combined cycle system. NASA has developed the underlying theory and technologies to enable this to occur, but demonstrating such a transition is a key enabler for a practical system. NASA will develop the underlying algorithms and techniques that will allow industry to implement this concept in a variety of systems and provide a flexible operational capability that does not exist today. Ultimately, such a system may allow more effective and flexible access to space.

Programs

AIRSPACE OPERATIONS AND SAFETY PROGRAM

AOSP develops and explores fundamental concepts, algorithms, and technologies to increase throughput and efficiency of the NAS safely. The program works in close partnership with the FAA and the aviation community to enable and extend the benefits of NextGen, the Nation's program for modernizing and transforming the NAS to meet evolving user needs. Integrated demonstrations of these advanced technologies will lead to clean air transportation systems and gate-to-gate efficient flight trajectories. The program is on the leading edge of research into increasingly autonomous aviation systems, including innovation in the management of UAS traffic and other novel aviation vehicles and business models. The program is also pioneering the real-time integration and analysis of data to support system-wide safety assurance, enabling proactive and prognostic aviation safety assurance. The program takes lead responsibility for three of ARMD's Strategic Thrusts:

- Thrust 1: Safe, efficient growth in global operations;
- Thrust 5: Real-time, system-wide safety assurance; and
- Thrust 6: Assured autonomy for aviation transformation (co-lead).

ADVANCED AIR VEHICLES PROGRAM

AAVP develops the tools, technologies, and concepts that enable new generations of civil aircraft that are safer, more highly energy efficient, and have a smaller environmental footprint. The program focuses on enabling major leaps in the safety, efficiency, and environmental performance of subsonic fixed and rotary wing aircraft to meet challenging and growing long-term civil aviation needs; pioneering low-boom supersonic flight to achieve new levels of global mobility; and sustaining hypersonic competency for national needs while advancing fundamental hypersonics research. In partnership with academia, industry and other government agencies such as the FAA, AAVP pioneers fundamental research and matures the most promising technologies and concepts for transition to system application by the aviation industry. The program also works in partnership with the DoD to ensure both NASA and DoD vehicle-focused research is fully coordinated and leveraged. The program sustains and advances key national testing capabilities that support aeronautics research and development needs. The program takes lead responsibility for three of ARMD's Strategic Thrusts:

- Thrust 2: Innovation in commercial supersonic aircraft;
- Thrust 3: Ultra-efficient commercial vehicles; and,
- Thrust 4: Transition to alternative propulsion and energy.

INTEGRATED AVIATION SYSTEMS PROGRAM

IASP focuses on experimental flight research and the spirit of integrated, technological risk-taking that can demonstrate transformative innovation. Therefore, the program complements both AOSP and the AAVP by conducting research on the most promising concepts and technologies at an integrated system level. The program explores, assesses, and demonstrates the benefits of these potential technologies in a relevant environment. The program works in partnership with the other Aeronautics programs, other government agencies, academia, the aviation industry, and international partners as appropriate. The program supports the flight research and demonstration needs across all six ARMD Strategic Thrusts. The program takes lead responsibility for the following Strategic Thrust:

- Thrust 6: Assured autonomy for aviation transformation (co-lead).

TRANSFORMATIVE AERONAUTICS CONCEPTS

The Transformative Aeronautics Concepts Program (TACP) cultivates multi-disciplinary, revolutionary concepts to enable aviation transformation and harnesses convergence in aeronautics and non-aeronautics technologies to create new opportunities in aviation. The program's goal is to demonstrate initial feasibility of internally and externally originated concepts to support the discovery and initial development of new, transformative solutions for all six ARMD Strategic Thrusts. The program provides flexibility for innovators to explore technology feasibility and provide the knowledge base for transformational aviation concepts by using sharply focused activities. The program solicits and encourages revolutionary concepts, creates the environment for researchers to become immersed in trying out new ideas, performs ground and small-scale flight tests, allows failures and learns from them, and drives rapid turnover into new concepts. The program also supports research and development of major advancements in cross-cutting computational tools, methods, and single discipline technologies to advance the research capabilities of all Aeronautics programs.

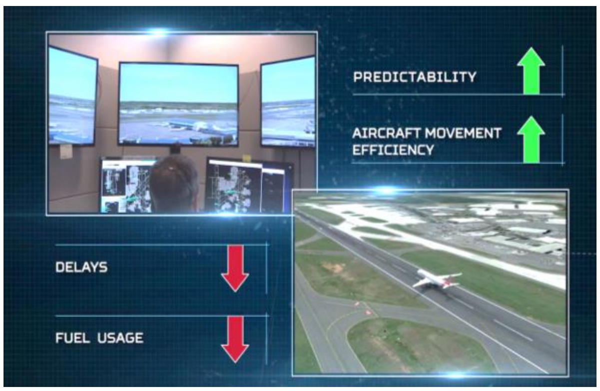
AIRSPACE OPERATIONS AND SAFETY PROGRAM

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**140.6**	**--**	**90.8**	**96.2**	**120.4**	**122.7**	**122.9**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



NASA's air traffic management technology enables improved flight schedule predictability and helps air traffic controllers increase efficiency in aircraft movement on the ground and during take-off. This results in reductions in flight delays, fuel usage, and noise.

The current U.S. air transportation system is widely recognized to be among the safest in the world. While the FAA-led NextGen effort will meet growing air traffic demand by enabling efficient passage through the increasingly crowded skies, it will come with increased operating complexity. Current aviation participants and the Air Traffic Management (ATM) system face many challenges related to global competitiveness, efficiency, productivity, higher mobility needs, and emergence of newer airspace uses (such as commercial space launches, and unmanned aircraft systems (UAS) in low and high altitudes).

Therefore, advanced automation technologies that work in harmony with human operators are critical for the United States to meet the public expectations for safety in this complex, dynamic domain. To achieve a modernized National Airspace System (NAS), the systems and processes of today must be rigorously and systematically transformed through the sustained, coordinated, and integrated efforts of many stakeholders. NASA looks to ensure that the future ATM system will accommodate these needs in a safe and affordable manner for service providers, vehicle/platform operators, and passengers as well as cargo. NASA will conduct research and develop autonomous technologies for aircraft/platforms as well as managing the airspace to support diverse operations. The transformation to modernize the NAS will be achieved through the deployment of new operational concepts and capabilities and advanced technologies, implemented in a service-oriented architecture for higher levels of commercial and automated services as applied to the Nation's air transportation system.

The Airspace Operations and Safety Program (AOSP) performs foundational air traffic management and operational safety research to enable continued improvement and transformation of the NAS. Moving key concepts and technologies from the laboratory into the field ultimately benefits the public by increasing capacity and reducing the total cost of air transportation.

AOSP (with the Federal Aviation Administration and its other industry and academic partners) conceives, develops, and demonstrates NextGen technologies to improve the intrinsic safety of current and future aircraft systems that will operate in the NAS.

AOSP aims to:

- Enable NextGen from gate-to-gate to support projected growth and reduce the total cost of air transportation operations. NASA will work to reduce operator workload, fuel consumption, and environmental impacts while identifying and mitigating safety risks under hazardous constraints in a manner that is scalable over time to meet operational growth.
- Enable safe operation of emerging aviation markets, including low altitude autonomous vehicles, such as urban air mobility (UAM) markets (small autonomous UAS up through passenger-carrying autonomous urban air taxis); high altitude, long endurance UAS; and, the potential reemergence of short-haul/thin-haul aviation. NASA will support the safe and efficient integration of traditional and emerging market operations, including high density, high frequency operations from many more access points in current low-density airspace.
- Enable more proactive system-wide "in-time" safety assurance management through the development of efficient tools and technologies to support real-time detection and mitigation of safety hazards, and assurance of new systems and operations.

NextGen technologies will provide advanced levels of automated support to air navigation service providers and aircraft operators for reduced travel times and travel-related delays both on the ground and in the sky. These advanced technologies provide shortened routes for time and fuel savings, with associated improvements in noise and emissions, and permit controllers to monitor and manage aircraft for greater safety in all weather conditions.

EXPLANATION OF MAJOR CHANGES IN FY 2019

AOSP will accelerate the technology transfer of the Air Traffic Management Technology Demonstration (ATD)-3 subproject in FY 2018 and conduct an early closeout in FY 2019. In FY 2018, ATD-3 will conduct and complete the planned Traffic Aware Strategic Aircrew Requests (TASAR) flight trial with Alaska Airlines. TASAR allows the pilots to request more efficient and direct routes around other aircraft traffic and weather from the cockpit. The results of the flight trial will allow the FAA to develop minimum standards and concepts of operation for air/ground integrated airline requested efficient routing. AOSP will coordinate with the FAA to allow for limited acceleration of the ATD-3 FY 2019 planned integration efforts into FY 2018.

In FY 2019, AOSP will complete an orderly closeout of the ATD-3 subproject, and transfer all data and research prototype tools to the FAA. NASA will deliver to FAA a Concept of Operations for Integrated Air/Ground user preferred routing utilizing NASA's TASAR, Dynamic Weather Routing (DWR), Multi-flight Common Routes (MFCR), and Dynamic Routes for Arrivals (DRAW), along with their research prototypes. FAA will use the technology transfer data to make their initial investment decision for integration of these capabilities into the FAA Time Flow Based Management (TBFM) system. The FAA will use the technology transfer data to make their initial investment decision for integration of these capabilities into the FAA Time Flow Based Management (TBFM) system.

ACHIEVEMENTS IN FY 2017

- NASA successfully completed ATM Technology Demonstration 1 (ATD-1). ATD-1 closeout activities occurred late FY 2017 after successful integration of the systems in the demonstration, final analysis, documentation, and technology transfer to the FAA. In September 2017, the ATD-

1 software, known as Terminal Sequencing and Spacing for Air Traffic Control, was named NASA's 2017 Software of the Year. (Thrust 1/ATD)

- NASA completed an initial air traffic simulation test bed for airspace systems that delivers capabilities to (1) evaluate emergent air traffic behavior due to novel air traffic control concepts and (2) provide the FAA and airspace users the ability to evaluate mature concepts/technologies in complex NextGen environments. (Thrust 1/Air Traffic Management – Exploration [ATM-X])
- NASA sponsored a study through the National Academies of Science, Engineering and Medicine, to develop a research agenda to support progress toward the vision of in-time safety assurance. In addition, NASA made progress on some of the fundamental challenges associated with moving toward in-time safety, including demonstration of a tool to verify streaming data and demonstration of tools to provide ongoing monitoring and assessment of safety margins for both in-flight and surface operations. (Thrust 5/System-Wide Safety [SWS])
- NASA developed, matured, and tested the second technical capability level (TCL2) for UAS traffic management (UTM) which incorporated weather/wind integration, trajectory routing, object avoidance, and congestion management in an initial flight trial at Nevada's Reno-Stead Airport. Researchers tested technologies that allowed dynamic adjustments to user-requested flight plans based on availability of airspace and contingency management. A NASA Technical Memorandum describing the demonstration of necessary data exchange between the UTM TCL2 components was included in the technology transfer to the FAA in April 2017. (Thrust 6/UTM)

WORK IN PROGRESS IN FY 2018

- NASA will begin the ATD-2 testing technologies that improve sharing of operational information to better plan and schedule aircraft movement. The ATD-2 computer-driven scheduling tools will help traffic managers coordinate flight schedules at the ramp, tower, terminal and center control facilities, and make better decisions about how to reduce congestion during the busiest times at airports and improve departure times saving fuel, time, and money. (Thrust 1/ATD)
- In support of developing urban air mobility operations, the ATM-X project will leverage NASA-developed technologies such as air traffic simulation test bed capabilities to evaluate automated trajectory negotiation, collaborative decision making, and connected trajectory-based technologies. NASA will also develop an Integrated Demand Management (IDM) concept that coordinates state-of-the-art capacity, demand, and weather forecasts across different traffic flow management capabilities to better regulate demand/capacity imbalances under adverse weather conditions. (Thrust 1/ATM-X)
- NASA is completing a safety assessment of selected air traffic management systems in a distributed environment and demonstrate a flexible framework for evaluating ATM and avionics systems. Upon successful demonstration, these tools will be transferred to the FAA and the avionics industry in FY 2019. NASA will simulate piloted models that support stall training requirements. NASA will also coordinate with the FAA and manufacturer research organizations to develop enhanced tools and methods to represent flight crew responses in situations associated with loss of energy state and/or attitude state awareness. (Thrust 5/SWS)
- NASA is developing and will demonstrate the third technical capability level (TCL3) for UTM, focusing on the requirements to manage separation by vehicle and/or ground-based capabilities under higher densities. The focus areas will be research validated under TCL2 demonstrating operations beyond the visual line-of-sight over moderately populated land with some interaction with manned aircraft. In addition, vehicle tracking/internet connectivity will enable validation of requirements for active monitoring of trajectory conformance. (Thrust 6/UTM)

KEY ACHIEVEMENTS PLANNED FOR FY 2019

- NASA will conduct the ATD-2 Phase 2 demonstration to evaluate the fused Integrated Arrival/Departure/Surface (IADS) system capability. Phase 2 will demonstrate the benefits of strategic surface metering during periods of significant demand/capacity imbalance and enhance tactical surface metering to improve non-movement area predictability and throughput. The ATD-2 capability will be expanded to validate more scheduling scenarios for the Washington and Atlanta Air Route Traffic Control Centers and will culminate in a Phase 3 full system Metroplex IADS demonstration in FY 2020. (Thrust 1/ATD)
- NASA will provide an initial demonstration of near real-time hazard identification by using a NASA-developed framework at the FAA to monitor and identify incident precursor patterns. Flight anomaly detection code will also undergo a final handoff and be integrated into daily operations at the FAA’s Aviation Safety Information Analysis and Sharing (ASIAS). In addition, NASA will develop a framework for representing and managing uncertainty in streaming aviation data. (Thrust 5/SWS)
- NASA will complete the final deliverables to the Commercial Aviation Safety Team, including delivering formal reporting methods to reduce risk of loss-of-control accidents (SE-200, “Virtual Day-Visual Meteorological Conditions Display Systems”) and an evaluation of display strategies to provide control guidance for recovery from approach-to-stall (SE-207, "Attitude, Energy State and Airplane Systems Awareness Technologies”). Closeout activities for the effort will be completed by fourth quarter FY 2019. (Thrust 5/SWS)
- NASA will develop and demonstrate the fourth and final technical capability level (TCL4) for UTM, focusing on large-scale UAS operations in higher-density urban areas. The demonstration will also test technologies that could be used to manage large-scale contingencies (i.e., communication/navigation failures, disaster scenarios, etc.). The focus areas will be all research validated under TCL3 (managing safe spacing of vehicles and ground-based capabilities under higher densities) over densely populated land with some interaction with manned aircraft. (Thrust 6/UTM)

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Program Elements

AIRSPACE TECHNOLOGY DEMONSTRATIONS (ATD)

The ATD project is comprised of a suite of critical technology development and demonstration activities geared toward delivery of near-term benefits to air transportation system stakeholders. ATD supports the ARMD safe efficient growth in global operations strategic thrust by two sub-projects with each focused on a technical challenge.

- ATD-1 (Interval Management - Terminal Area Precision Scheduling and Spacing) will directly address terminal area congestion, and evaluate the benefits of advanced flight arrival management technologies across a range of aircraft equipment levels during moderate to high levels of traffic demand. When integrated, the ATD-1 technologies will allow the pilots to achieve precise spacing separation between aircraft, and the controllers to manage the variability between flights and respond to disturbances to the schedule. This integrated set of capabilities will enable increased fuel efficiency while maintaining runway throughput to high-density airports.
- The Integrated Arrival, Departure, Surface (IADS) technology demonstration will develop and demonstrate an integrated suite of tools to provide the FAA and airline operators precision schedules for gates, runways, arrival, and departure fixes while ensuring efficient individual aircraft routes. IADS, also known as ATD-2, will reduce unnecessary buffers imposed by the human workload associated with the tasks of simultaneously coordinating and scheduling of arrivals, departures, and runway and surface operations.

AIR TRAFFIC MANAGEMENT - EXPLORATION (ATM-X)

The Air Traffic Management - eXploration (ATM-X) project will transform the air traffic management system to accommodate the growing demand of new entrants with their new mission requirements while also allowing established large commercial aircraft operators to fly more user-preferred routes with improved predictability. To achieve the goal of greater universal access with safe efficient operations for all users and allow for more flexible flight routes, ATM-X will utilize a two-phase approach.

In the first phase, the project will explore challenging use cases (e.g., high-density vertical lift vehicle operations for urban air mobility (UAM)) in an open airspace management system architecture to establish key performance parameters and prioritized technical challenges. Phase 1 will also provide early demonstration of emerging market operations by simulating higher levels of industry-provided services to validate the potential for more rapid modernization by incorporating innovations at "industry" speeds.

Phase 2 will then pursue the baselined technical challenges and further develop, validate and transfer the key concepts and technologies to stakeholders. Phase 2 will also demonstrate that the open architecture approach, integration of air traffic technologies, system-wide data use, and advances in human-machine teaming and increasingly autonomous decision-making will provide comprehensive situational awareness and improved coordinated decision-making and disruption management using advisories to enable flexible, user-preferred, predictable, and robust operations. ATM-X will leverage the FAA’s infrastructure modernization investments and NASA’s Airspace Technology Demonstrations, as well as the NASA Test Bed (which will also provide a common simulation platform with the System-Wide Safety project, thereby enabling areas of overlapping requirements such as disruption management to be achieved collaboratively) to support research. The air traffic simulation test bed will provide the building blocks to enable all current and future ARMD airspace operations simulations.

SYSTEM-WIDE SAFETY (SWS)

The SWS project will perform research to (1) explore, discover, and understand the impact on safety of the growing complexity introduced by advances aimed at improving the efficiency of flight, the access to airspace, and/or the expansion of services provided by air vehicles; and (2) develop and demonstrate innovative solutions that enable these advances, and the aviation transformation envisioned by ARMD, through proactive mitigation of risks in accordance with target levels of safety. The project will develop tools, methods and technologies to enable capabilities envisioned by ARMD's Strategic Thrust 5, Real-Time System-Wide Safety. The following conditions expand system safety awareness:

- increased access to relevant data;
- integrated analysis capabilities;
- improved real-time detection and alerting of hazards at the domain level;
- decision support, and in some cases; and
- automated mitigation strategies.

The System-Wide Safety project also addresses the need, identified in Strategic Thrusts 1 and 6, for safety-related advances in methods used for the verification and validation of advanced increasingly autonomous systems.

SWS research and development achieves its two-fold goal by developing and demonstrating:

- An integrated risk assessment capability that continuously monitors airport terminal area safety margins and recommends timely operational changes based on data analytics and predictive models derived from large heterogeneous data sets and their time histories;
- Dependable monitoring, assessment and mitigation capabilities for safety-critical risks to beyond visual line-of-sight low altitude unmanned aircraft operations near populated areas;
- Cost-efficient verification and validation methods that provide justifiable confidence in safety claims for designs of complex ATM/avionics systems, including increasingly autonomous, non-deterministic systems; and
- On-board systems and new training capabilities that reduce susceptibility to precursor conditions that have led (and can lead) to aircraft loss-of-control accidents in commercial aviation.

UAS TRAFFIC MANAGEMENT (UTM)

In support of ARMD's strategic thrust toward assured autonomy for aviation transformation and safe, efficient growth in global operations, the UTM project will conduct research and development activities to ensure that the future airspace management system will initially accommodate small UAS operating in low-altitude airspace beyond the visual line of sight with far greater levels of system complexity. The airspace management system will need to accommodate greater diversity of aircraft performance, user business models, and airspace requirements for these emerging airspace users. The system must also ensure scalability of operations, and affordability for service providers and users. The fundamental objective of the UTM project is to develop technologies, roles, responsibilities, and procedures to demonstrate feasibility of autonomous aircraft operations in populated areas. This development must enable autonomous traffic flow management that allows more robust decision-making in the presence of weather forecast uncertainties, developing alternative plans and dynamically changing the plans as forecasts change, and using learning algorithms/automation based on historical analysis of performance.

Program Schedule

Date	Significant Event
Mar 2018	UTM – Initiate TCL3 to incorporate TCL2 research and to manage separation by vehicle and/or ground-based capabilities under higher densities.
Apr 2018	ATM-X – Develop a UAM concept of operations and an initial UAM system architecture
Jun 2018	SWS – Validate technologies to enhance flight crew attitude and energy state awareness
Jun 2018	SWS – Validate human fatigue monitoring tool publicly available in the Apple App Store; demonstrate code analysis techniques on airspace management software at the FAA; define requirements for classes of autonomy algorithms involving learning and or optimization and develop (semi-) automated tools for checking these requirements
Aug 2018	SWS – Demonstration of safety countermeasures for spatial disorientation and attentional performance limitations in relevant environment at the DoD Naval Medical Research Unit Disorientation Research Device facility.
Sep 2018	SWS – Anomaly detection tool with active learning integrated into ASIAS vulnerability database and demonstrated to work with FAA Threaded Track data
Jan 2019	ATM-X – Flight test demonstration of automated system negotiation and trajectory management
Mar 2019	SWS – Evaluation of displays and predictive alerting algorithms that indicate systems status and the interaction of systems in time-critical situations involving system failures
Jun 2019	UTM – Initiate TCL4 to incorporate TCL3 research and to manage large-scale contingencies.
Jun 2019	SWS – Demonstrate use of RACE framework at FAA to monitor and identify incident precursor patterns in-time; develop foundations for mitigation of residual risk in autonomous algorithms
Sep 2019	SWS – Develop a safety assurance dashboard that can give a comprehensive view of retired and residual risks.
Aug 2019	ATM-X – Development of UAM Services dynamic scheduling and congestion management operations.
Sep 2019	ATM-X – Release of the NASA Test Bed Build 2 with modeling of emergent vehicles and missions
Dec 2019	ATM-X – Simulation demonstration of the Integrated Demand Management concept of operations with weather disruptions
Jun 2020	ATD – Full-system demonstration of the IADS metroplex departure scheduling concept. SWS – Demonstration of tools for identifying, measuring, and tracking proximity to a variety of heterogeneous safety margins during airport terminal area operations.
Sep 2020	ATM-X – Human-in-the-loop simulation of mixed legacy and new entrants interacting in controlled airspace

Program Management & Commitments

Program Element	Provider
ATD	Provider: ARC, Langley Research Center (LaRC), GRC Lead Center: ARC Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): FAA, Honeywell, General Electric, Boeing, Raytheon, Rockwell Collins, Goodrich, Cessna Aircraft Co., American Airlines, United Airlines, EasyJet, Southwest Airlines, DoD, French Aerospace Lab (ONERA)
ATM-X	Provider: ARC, LaRC, GRC Lead Center: ARC Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): FAA, American Airlines, Boeing, Delta Airlines, General Electric, Southwest Airlines
SWS	Provider: ARC, LaRC, GRC Lead Center: LaRC Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): FAA, DoD-AFRL, DoD-NAMRU, NRC, NITRD, Rockwell-Collins, Honeywell, Boeing, American Airlines, Commercial Aviation Safety Team, Unmanned Aircraft Safety Team
UTM	Provider: ARC, LaRC, GRC Lead Center: ARC Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): FAA, DHS, DoD, AeroVironment, Amazon, AT&T, Google, AirMap, Aurora, General Electric, Gryphon Sensors, Intel, Qualcomm, Rockwell Collins, Simulyze, Verizon, JAXA

Acquisition Strategy

The AOSP spans research and technology from foundational research to integrated system capabilities. This broad spectrum necessitates the use of a wide array of acquisition tools relevant to the appropriate work awarded externally through full and open competition. Teaming among large companies, small businesses, and universities is highly encouraged for all procurement actions.

MAJOR CONTRACTS/AWARDS

NASA's Aeronautics programs award multiple smaller contracts, which are generally less than $5 million. They are widely distributed across academia and industry.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Formulation: ATM-X and SWS Projects	ARMD Senior Management and Expert Review	Sep 2017	The Key Decision Point (KDP) Formulation Review evaluates the projects' goals and stated deliverables to ensure proper formulation and alignment with Agency and ARMD strategic objectives. The review assesses the competence of technical challenge pre-formulation efforts.	ATM-X passed preliminary KDP-A review and was approved to continue formulation planning for final KDP-C approval. SWS approved for FY 2018 execution in final KDP-C review.	Early Spring 2018
Performance (Annual)	Expert Review	Oct 2017	The 12-month review is a formal independent peer review. Experts from other government agencies report on their assessment of technical and programmatic risk and/or program weaknesses.	Determined that the projects made satisfactory progress in meeting technical challenges and met all annual performance indicators.	Oct 2018

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	274.6	--	230.6	248.5	257.1	257.8	258.3

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

The Boundary Layer Ingestion (BLI) Inlet Distortion Tolerant Fan (DTF) installed in NASA GRC's 8'x6' wind tunnel , a new capability to investigate fuel burn reduction potential by embedding an aircraft's engine at the rear of an aircraft compared to an under the wing conventional configuration.

AAVP develops knowledge, technologies, tools, and innovative concepts to enable safe new aircraft that will fly faster, cleaner, quieter, and use fuel far more efficiently than in the past. NASA research is incorporated into all major modern U.S. aircraft, and the type of research performed by AAVP will prime the technology pipeline, enabling continued U.S. leadership, competitiveness, and high-quality jobs in the future. Technologies and design capabilities developed for these advanced vehicles will integrate multiple, simultaneous vehicle performance considerations including fuel usage, noise, emissions, and intrinsic safety. Efficiency and environmental factors will play a significant role as the aviation market expands across the globe in which the technologies developed by AAVP will help ensure continued U.S. leadership that also benefits the world. Across the program, NASA will continue to engage partners from industry, academia, and other government agencies to maintain a sufficiently broad perspective on technology solutions to these challenges; to pursue mutually beneficial collaborations; and to leverage opportunities for effective technology transition.

AAVP directly supports three of the ARMD Strategic Thrusts:

- Thrust 2: Innovation in Commercial Supersonic Aircraft
- Thrust 3: Ultra-efficient Commercial Vehicles
- Thrust 4: Transition to Alternative Propulsion and Energy

In addition, the Program is responsible for advancing key hypersonic technologies for the country and enabling ground test capabilities that support the research, technology demonstration, and validation requirements of NASA, other government agencies, and commercial partners.

EXPLANATION OF MAJOR CHANGES IN FY 2019

Funding for hypersonic research will increase by $5 million, which will allow NASA to better engage the community for fundamental research and also mitigate some potential issues with key ground test infrastructure. Recently, NASA made key infrastructure investments that have brought additional capabilities that support research and also mitigate the risk of a significant mechanical issue, but additional facility issues remain that will now be addressed. The funding will allow additional experimentation and strengthening of key partnerships that will allow NASA to capitalize on recent successes and accelerate research in select areas that are important to the U.S. hypersonics community.

ACHIEVEMENTS IN FY 2017

- NASA reached a major milestone for commercial supersonic aircraft by developing "Intermediate Tools for Sonic Boom Community Reponses" which represents a key step for enhancing computational tools to aid in understanding the impact of noise from sonic booms. These tools are needed to help ensure that the best noise data are obtained and also to project the effects to a wider variety of locations because it would not be possible to actually fly a low boom aircraft over every community. Ultimately, this research will assist in the ability to establish a new low boom regulation that opens the door to a commercial supersonic transport market. (Thrust 2/Commercial Supersonic Technology Project [CST])
- In addition to developing computational tools, NASA made significant progress during FY 2017 on the Low Boom Flight Demonstration (LBFD) project. In FY 2017, NASA successfully completed the preliminary design for the LBFD test aircraft. This effort addressed integration of all aspects of a design that enables the mission requirements of the LBFD to be met. Scaled models of the design were tested in the NASA Glenn Research Center wind tunnels in 2017 to validate the performance against the project requirements. (Thrust 2/CST)
- At NASA's Glenn Research Center 8' x 6' wind tunnel, NASA completed the installation of a Boundary Layer Ingestion (BLI) System. The BLI system will enable radical reductions in fuel burn, and noise reductions for future generations of aircraft, primarily by reducing the amount of drag created by conventionally mounted engines. This new capability was proven to be successful during a collaborative effort between NASA and United Technologies Research Center with the completion of the first-ever transonic wind tunnel test of a new gas turbine engine fan design that could withstand the distorted air inflow due to BLI with minimal effect on fan performance and stability. These experiments assisted in the quantification of the BLI impact on fan performance and structural characteristics at cruise conditions. (Thrust 3/Advanced Air Transport Technology Project [AATT])
- NASA completed the assessment and initial development of computational tools that would accurately predict the strength and life of composite designs. In addition, NASA also advanced key technologies to rapidly test and inspect composite structures for possible damage. (Thrust 3/Advanced Composites Project [ACP])
- NASA, in partnership with the US Army and Penn State University, has successfully designed, patented and fabricated two innovative two-speed transmission systems for vertical lift vehicles, the Dual-Star Idler and the Offset Compound Gear. This new technology enables a turbine engine to continue to operate efficiently even while its internal speed is slowed down. Also, NASA developed and patented new hybrid metal/composite gears to reduce transmission system weight compared to current all-metal systems. The ability to slow a rotor provides a long sought-after capability for vertical lift vehicles that allows significant improvements in performance and reduction of noise. The reduction in weight resulting from the use of lightweight hybrid

component technologies could be applied beyond vertical lift to other aviation vehicles and the automotive industry. (Thrust 3/Revolutionary Vertical Lift Technology Project [RVLT])

- NASA worked with airframe and engine manufacturers as well as universities to identify and analyze propulsion and power system options for next generation aircraft. These analyses verified the benefits of the new propulsion systems for a single aisle class of transport airplane and will be used to guide the technology development efforts on specific components. For example, turboelectric and hybrid electric designs are showing promising energy reductions of up to 15 percent for the propulsion system alone, which can also be augmented by improvements in other technologies, such as materials and wing design. (Thrust 3/AATT)
- NASA, along with its partner, Boeing, made substantial progress in advancing technologies aimed at hybrid electric propulsion for large commercial aircraft by completing system-level assessments of several promising hybrid electric/turboelectric concepts. All concepts that were assessed showed significant reductions in fuel burn compared to conventional aircraft. In additions, NASA designed high-efficiency and high specific power megawatt-scale powertrain components such as the electric motors/generators and power converters. (Thrust 3/AATT)
- In addition to the design and advancement of components to enable all-electric or hybrid gas-electric propulsion systems, NASA investigated small-core combustion engine technologies. The collective effect of this research is the potential for low or nearly no carbon emission propulsion advancements. In the area of advanced combustors, NASA and United Technologies Research Center completed initial single-sector concepts for the 2035 timeframe focusing on lowering emissions, fuel flexibility, and advancing small core combustor architectures that reduces landing and take-off nitrogen oxides by 80 percent below the standards set by the International Civil Aviation Organization and its committee on Aviation Environmental Protection in 2010. (Thrust 3/AATT)
- NASA improved utilization of critical aerosciences ground test infrastructure, made up of 12 large wind tunnels and other facilities. The improvement was from implementing a new funding model that encourages use of these facilities for space vehicle and spacecraft validation testing, mission risk reduction testing, and foundational experimental research necessary to advance our computational tools and innovative concepts. (Cross Cutting/AETC)
- NASA completed a diverse set of hardware modifications in the Ames Unitary Plan Wind Tunnel creating an "Optical Test Section of Tomorrow". For this transonic/supersonic wind tunnel, the modifications will improve the data acquisition system for test model surface pressures and off-body aerodynamic measurements, and also increase productivity and data accuracy through advanced optical instrumentation and techniques. This new capability will allow researchers to accurately and efficiently identify and understand the complex flow phenomena of next generation aircraft and space vehicles in realistic flight conditions. (Cross Cutting/ Aerosciences Evaluation and Test Capabilities [AETC])
- In FY 2017, NASA started the Hypersonic Technology Project to develop synergistic technology and knowledge that benefit NASA's long-term interests for commercial applications while leveraging Department of Defense interests. During the year, NASA completed an assessment of approaches to better estimate the uncertainty of models and designs of hypersonic systems. These approaches will be applied to computer models and validated with ground test and flight data. Ultimately, this will lead the way to new design tools that facilitate the development of a variety of hypersonic vehicles. Additionally, NASA conducted tests that improved the project's understanding of how to develop a high-speed propulsion system that can take off like a traditional jet airplane and transition to a scram jet for increased speed. NASA is researching how to optimally make this transition and is developing tools and guidance that others can eventually use to design reusable hypersonic vehicles. (Hypersonic Technology Project [HYP])

WORK IN PROGRESS IN FY 2018

- NASA is continuing development of additional models for the prediction of the community response to noise created by the overflight of future supersonic commercial aircraft. Based on simulations conducted in NASA's Interior Effects Laboratory, the first of these models will be capable of predicting the response of a person who hears supersonic overflight noise while indoors. The second of these models will be used to predict the indoor noise created by supersonic overflight in a wide variety of homes with different room arrangements and construction techniques. With the combination of these models, NASA will perform analytical studies of community responses to the overflight noise of future supersonic commercial aircraft, which will provide the underlying data needed for NASA to develop future community overflight experiments. (Thrust 2/CST)
- NASA is continuing to investigate the potential benefits of the integrated Boundary Layer Ingestion technology for engines that can be mounted and partially embedded, on top of an airframe in a way that is much more efficient than traditional under-the-wing engine configurations. Recent boundary layer ingestion test results show an overall vehicle efficiency benefit. (Thrust 3/AATT)
- In order to help improve the performance, efficiency, and noise reduction for new higher-speed vertical lift configurations, NASA is demonstrating Multi-Fidelity Design Optimization processes for low-noise and low-emissions Vertical Take Off and Landing (VTOL) designs. The ability to use computational optimization processes will enable design engineers to efficiently assess and compare design and technology options to create advanced concepts for cleaner and quieter VTOL configurations. These advances will help pave the way for new vehicles that can be used for new missions such as economical inter-urban transport. (Thrust 3/RVLT)
- NASA will continue to partner with universities, industry, and other government agencies to investigate, develop, and test small-core, fuel-flexible combustor technologies that take full advantage of the attributes of alternative drop-in jet fuels. These advanced technologies have the potential to reduce nitrogen oxide emissions and particulate matter pollutants to 80 percent below the international standard with minimal impacts on weight, noise and component life. (Thrust 4/AATT)
- NASA, in partnership with United Technologies Research Center, Pratt and Whitney, and Woodward, will continue studying newly designed small-core combustors in order to obtain landing and take-off nitrogen oxide emissions data at relevant engine operating conditions. In addition, NASA will continue to focus on establishing a viable concept for a 5-10 megawatt hybrid gas-electric propulsion system for commercial transport aircraft focusing on demonstrating an overall system-level energy usage reduction. (Thrust 4/AATT)
- NASA is working on the NASA Electric Aircraft Testbed (NEAT) in preparation of installing and demonstrating a megawatt-class powertrain in FY 2019. NASA developed the NEAT facility to enable ambient and cryogenic powertrain research and technology development for electric aircraft systems at power levels relevant to full-scale, single-aisle aircraft. (Thrust 4/AATT)
- NASA will complete the design and installation of a new acoustical treatment in the Glenn Research Center 9x15-Foot Low-Speed Wind Tunnel. This improvement will further reduce the facility background noise to levels that will enable testing of next-generation low-noise propulsion system concepts. (Cross Cutting/AETC)
- NASA will conduct ground test experiments to advance the feasibility of future systems that could use a turbine engine at slow speeds and then transition to a scramjet for high-speed operations. In addition, NASA will perform fundamental research in the areas of high-speed propulsion, re-usable vehicle technologies, and high-temperature materials. Systems analysis will also be performed greatly increasing the flexibility and utility of high-speed vehicles. (HYP)

KEY ACHIEVEMENTS PLANNED FOR FY 2019

- NASA will complete a "Sonic Boom Community Response Metric and Methodology" technical challenge by validating field study methodology, including indoor and outdoor noise metrics, exposure estimates, survey tools, and test protocols to support community studies for a low-boom flight demonstration. (Thrust 2/CST)
- NASA will explore a concept of tailoring aircraft structures so that weight is minimized in areas where it is not needed. NASA will focus on completing three key technical challenges in the area of accurate strength and life prediction, rapid inspection and characterization, and efficient manufacturing process development to help demonstrate the viability of this concept. An important milestone will also be accomplished by demonstrating computer-based tools, methodologies and system-level assessments which will reduce the time required to develop and certify composite structures. (Thrust 3/AATT)
- AAVP will complete a technical challenge in the area of Higher Aspect Ratio Wing to enable up to a doubling of the aspect ratio of a lightweight wing with safe structures and flight controls. Testing and analysis results will contribute to quantifying the system-level benefits of the Transonic Truss Braced Wing concept. (Thrust 3/AATT)
- NASA will lay the foundation for establishing a new multi-disciplinary design capability that will benefit a wide variety of vertical lift vehicle sizes. This new design approach will enable industry to develop conceptual designs of advanced vertical lift vehicles while taking into account multiple disciplines and aspects of the configuration design. Additionally, a focus in FY 2019 will be to complete a technical challenge for demonstrating design and flight operation methods for reducing VTOL aircraft noise impact, while accomplishing a milestone for achieving noise reductions of at least five decibels (dB) on approach for VTOL tests designed for low noise. (Thrust 3/RVLT)
- NASA will complete the Advanced Composites project which will deliver a variety of computational tools and guidance that will significantly reduce the time needed to develop new composite structures for aerospace applications. Currently, it is a time-consuming process to develop these new structures because of significant testing that is needed. The goal of the program is not to eliminate testing, but rather supplement such testing more effectively with computational models that will allow industry to test smarter and more efficiently, thus reducing the development time by up to 30 percent which will also reduce the cost significantly. (Thrust 3/ACP)
- NASA will establish a viable concept for 5-10 MW hybrid gas-electric propulsion system required for commercial transport aircraft. A main focus area is the superconducting motor component, which represents a major advancement in a key technology needed to realize practical larger-scale hybrid electric propulsion systems for the future. Further, in partnership with industry, NASA will advance a MW-scale non-superconducting inverter to a higher technical maturity level. This advancement complements the superconducting motor and adds to the technology options available to hybrid electric propulsion system designers as they identify and develop larger ground and flight demonstration opportunities. (Thrust 4/AATT)
- NASA will complete a technical challenge in the area of Low Nitrogen Oxide Fuel-Flex Combustion for advanced small core engines focusing on reducing Nitrogen Oxide emissions from fuel-flexible combustors to 80 percent below the CAEP/6 standard with minimal impacts on weight, noise, and component life. NASA will identify, evaluate, and develop technologies and methods to enable small-core architectures to perform well at high-pressure conditions along with focusing on challenges associated with low emissions, scaling barriers, fuel-injection, thermal management, auto-ignition, and combustion dynamics. (Thrust 4/AATT)
- NASA will complete a series of new capabilities and test technologies for several wind tunnels. NASA's Propulsion Systems Laboratory will confirm its capability that can simulate the high ice

water content cloud conditions experienced in nature to the degree required to simulate aviation safety issue of engine icing. (Cross Cutting/AETC)

- NASA will conduct a key experiment to demonstrate an autonomous mode transition in a turbine-based combined cycle system. NASA has developed the underlying theory and technologies to enable this to occur, but demonstrating such a transition is a key enabler for a practical system. NASA will develop the underlying algorithms and techniques that will allow industry to implement this concept in a variety of systems and provide a flexible operational capability that does not exist today. Ultimately, such a system may allow more effective and flexible access to space. (HYP)

Program Elements

ADVANCED AIR TRANSPORT TECHNOLOGY

NASA's vision for advanced fixed wing subsonic commercial transport aircraft addresses the comprehensive challenges of revolutionary advances in energy efficiency and environmental compatibility of future generations of aircraft. These technological solutions are critical to reduce the impact of aviation on the environment even as this industry and the corresponding global transportation continue to grow. Research will explore and advance knowledge, technologies, and concepts to enable major steps in energy efficiency and environmental compatibility resulting in less fuel burned, less direct impact on the atmosphere, and less noise around airports. This project will identify and address potential new safety considerations associated with these advanced technologies and concepts. This research supports the sustained growth of commercial aviation. The knowledge gained from this research, in the form of experiments, data, system studies, and analyses, is critical for conceiving and designing more efficient, quieter aircraft. Advanced air transport research directly supports ARMD Strategic Thrusts 3 and 4 and focuses on developing advanced technologies and tools for future generations of commercial transports – including the core propulsion research needed to develop new engines that will ultimately power the new vehicles. Although this project focuses on the far-term technology timeframe, it also contributes to both near- and mid-term by demonstrating interim technology advancements.

REVOLUTIONARY VERTICAL LIFT TECHNOLOGY

The NASA Revolutionary Vertical Lift Technology (RVLT) project develops and validates tools, technologies, and concepts to overcome key barriers to the expanded use of vertical lift vehicles in the Nation's airspace. The unique ability of vertical lift vehicles to hover has significant applications in the civil market for human and cargo transportation, delivery systems, inspection and surveillance missions, oil and gas exploration, disaster relief and many more critical operations. RVLT research advances technologies that will increase speed, range, payload, and safety as well as decrease noise, weight, and fuel and energy usage. To accomplish this research, NASA uses advanced computer-based multi-fidelity prediction methods, unique NASA facilities, and state-of-the art experimental techniques. RVLT considers current and future vertical lift vehicles of all classes and sizes, ranging from very small configurations to configurations that are viable commercial transports in the NAS. Advanced future vertical lift vehicles of all classes and sizes will require higher speed capability and improved operational efficiency. For example, the project is currently working with the Transformative Aeronautics Concepts Program to explore ideas that may combine autonomy and hybrid/ full electric propulsion systems with a vertical lift capability to enable a variety of new civil missions. The RVLT project primarily supports ARMD Strategic Thrust 3.

COMMERCIAL SUPERSONIC TECHNOLOGY

Supersonic vehicle research includes tools, technologies, and knowledge that will help eliminate today's technical barriers to practical, commercial supersonic flight. These barriers include sonic boom, supersonic aircraft fuel efficiency, airport community noise, high altitude emissions, vehicle aeroservoelastic design, supersonic operations, and the ability to design future vehicles in an integrated, multidisciplinary manner. Research conducted will establish the necessary approaches and techniques for objectively measuring the levels of sonic boom acceptable to communities living in the vicinity of future commercial supersonic flight paths. These approaches, techniques, and resulting data will inform both national and international regulatory organizations that set the standards for commercial entities and vehicles to achieve. The research also lays the groundwork for overcoming other challenges facing commercial supersonic flight including energy efficiency, reduced pollutants emitted into the atmosphere, and acceptable engine noise levels in the airport area. The Commercial Supersonic Technology project directly supports ARMD Strategic Thrust 2 and will conduct the research leveraging the purpose-built Low Boom Flight Demonstrator in conducting the community response mission.

ADVANCED COMPOSITES

NASA is addressing new test protocols and methods to reduce the development and certification timeline for composite materials and structures. Composite structures will see increased application due to the pressure to develop more efficient, sustainable vehicles due to weight and life cycle cost savings that composite technologies can offer. Testing is the primary basis of the present approach for the development and certification of composites. It is both time-consuming and expensive but can provide rigorous validated results. NASA will focus on the development and use of high fidelity and rigorous computational methods, improved test protocols, and standardized inspection techniques to shorten the timeline to bring innovative composite materials and structures to market. NASA engages with key players from Government (Federal Aviation Administration and Department of Defense), industry, and academia to mature and verify the methodology, to ensure effective transition to industry, and to assure safety for certification authorities. The goal of the project is to reduce the estimated five- to nine-year timeline for composite structures development and certification by thirty percent. The Advanced Composites project directly supports ARMD Strategic Thrust 3 because of its ability to drive future competition for high-tech manufacturing and revolutionary technologies bringing composites to the market faster while addressing the need for ultra-efficient commercial transport advancements. In addition, the project is applicable to Thrust 2 because future supersonic aircraft will likely make significant use of composites.

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

The ground test capabilities (facilities, systems, workforce, and tools) necessary to achieve the future air vehicles and operations described above require efficient and effective investment, use, and management. Efforts in this area preserve and enhance those specific ground test capabilities that are necessary to achieve the missions. Among these assets are subsonic, transonic, supersonic, and hypersonic wind tunnels and propulsion test facilities at the Ames Research Center in Mountain View, CA, the Glenn Research Center in Cleveland, OH, and the Langley Research Center in Hampton, VA. These test facilities and capabilities also serve the needs of non-NASA users. NASA's integrated approach to test capability planning, use, and management will consider the complementary computational tools, software, and related systems to effectively acquire and process research data. NASA also offers research customers high-quality data that accurately reflect the simulated test environment and the interactions of test articles in those test environments in conjunction with the ground experimentation capabilities.

Furthermore, NASA expertise helps ensure safe and successful use of the assets and high quality of the research outcomes. The project is cross-cutting and supports ARMD Strategic Thrusts 2, 3, and 4 as well as other Agency efforts and those of key industry partners.

HYPERSONIC TECHNOLOGY PROJECT

The development of new hypersonic capabilities is important for the country. In the near-term, application of hypersonic technologies is likely to be on enhanced defense systems, but this could eventually expand to include improved access-to-space capabilities that would directly benefit NASA. NASA maintains unique specialized facilities and experts who will focus on key fundamental research areas that explore key challenges in very high-speed flight. This project will coordinate closely with partners in the Department of Defense so that NASA can leverage their investment in flight activities to develop and validate advanced physics-based models and at the same time, the Department of Defense can benefit from NASA expertise, analyses, testing capabilities and computational models. Focus areas for the project include high-speed propulsion systems, re-usable vehicle technologies, high-temperature materials, and systems analysis.

Program Schedule

Sep 2017	AATT – Complete Integrated BLI System technical challenge
Sep 2017	AETC – Complete the replacement of the facility control system and steady state data acquisition systems at both the GRC 8x6-Foot Supersonic Wind Tunnel and 9X15-Foot Low Speed Wind Tunnel to enable world-class steady state data capabilities including higher reliability, channel count, processing rates, analyses, improved plotting, a higher reliability, and more versatile control system.
Sep 2017	RVLT – Demonstrate a two-speed drive system for vertical lift applications that can operate with a 50 percent shaft speed change and efficiently transfer high torque with no weight penalty.
Sep 2017	RVLT – Complete functional checkout and assessment of the Tiltrotor Test Rig (TTR) to demonstrate a new test capability for high-speed vertical lift configurations.
Sep 2018	AETC – Complete Reduce Background Noise Levels for Engine System Noise Measurements (GRC 9- X 15- Foot Low Speed Wind Tunnel) capability challenge
Sep 2018	AATT – Complete Fan & High-Lift Noise technical challenge
Sep 2018	AATT – Completion of Low NOx Fuel-Flex Combustor technical challenge
Sep 2019	RVLT – Complete the technical challenge for demonstrating a Multi-Disciplinary Analysis Optimization (MDOA) process for Vertical Lift Vehicles
Sep 2019	AATT – Complete Higher Aspect Ratio Wing (HARW) technical challenge
Sep 2019	AATT – Complete Hybrid Gas-Electric Propulsion Concept technical challenge
Sep 2019	AC – Complete Accurate Strength & Life Prediction technical challenge
Sep 2019	AC – Complete Rapid Inspection & Characterization technical challenge
Sep 2019	AC – Complete Efficient Manufacturing Process Development technical challenge
Sep 2019	AETC – Complete Optical Instrumentation for Advanced Flowfield Measurements Needed for Next Generation Computational Simulation Development and Validation capability challenge
Sep 2019	AETC – Complete Force Balance Repeatability and Accuracy to Accommodate Needs of Advanced Aircraft Design Wind Tunnel Models capability challenge
Sep 2019	AETC - Integrated, NIST-Traceable Calibration and Characterization of Wind Tunnel Facilities capability challenge
Sep 2019	CST- Complete the Sonic Boom Community Response Metric & Methodology technical challenge.

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Sep 2017	AETC – Complete the replacement of the facility control system and steady state data acquisition systems at both the GRC 8x6-Foot Supersonic Wind Tunnel and 9X15-Foot Low Speed Wind Tunnel to enable world-class steady state data capabilities including higher reliability, channel count, processing rates, analyses, improved plotting, a higher reliability, and more versatile control system.
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Sep 2019	AETC – Complete Optical Instrumentation for Advanced Flowfield Measurements Needed for Next Generation Computational Simulation Development and Validation capability challenge
Sep 2019	AETC – Complete Force Balance Repeatability and Accuracy to Accommodate Needs of Advanced Aircraft Design Wind Tunnel Models capability challenge
Sep 2019	RVLT- Complete the demonstration design of flight operation methods for reduced Vertical Take-Off and Landing (VTOL) aircraft noise impact.

Program Management & Commitments

Program Element	Provider
Advanced Air Transport Technology (AATT)	Provider: ARC, Armstrong Flight Research Center (AFRC), GRC, LaRC Lead Center: GRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): U.S. Air Force, Boeing, Pratt & Whitney, Northrop Grumman, General Electric Aviation, Aurora, United Technologies Corporation, Rolls Royce/Liberty Works, Honeywell, FAA, Lockheed Martin, Exa Corp, U.S. Navy, DLR, U.S. small business and universities
RVLT	Provider: ARC, GRC, LaRC Lead Center: LaRC Performing Center(s): ARC, GRC, LaRC Cost Share Partner(s): FAA, UTRC, U.S. Army, DLR, U.S. Navy, Sikorsky Aircraft, U.S. small businesses and universities
Commercial Supersonic Technology	Provider: ARC, GRC, LaRC, AFRC Lead Center: LaRC Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): Boeing, General Electric Aviation, Gulfstream Aerospace, U.S. Air Force, FAA, JAXA, HoneywellRockwell, Collins, Lockheed Martin, U.S. Navy, U.S. small businesses and universities
Advanced Composites	Provider: ARC, GRC, LaRC Lead Center: LaRC Performing Center(s): ARC, GRC, LaRC Cost Share Partner(s): Boeing, General Electric Aviation, Lockheed Martin, , United Technologies Corporation, Collier, Aurora, Orbital ATK, NIA, FAA, WSU, USC, , Spirit Aerosystems
Aerosciences Evaluation and Test Capabilities	Provider: ARC, GRC, LaRC Lead Center: N/A Performing Center(s): ARC, GRC, LaRC Cost Share Partner(s): DoD
Hypersonic Technology	Provider: GRC, LaRC Lead Center: LaRC Performing Center(s): AFRC, GRC, and LaRC Cost Share Partners: DoD, Boeing, Lockheed Martin, Aerojet Rocketdyne, Orbital ATK, Northrup Grumman, Rolls Royce Liberty Works, SPIRITECH, ACENT, and Williams International

Acquisition Strategy

Research and technology spans from foundational research to integrated system capabilities. This broad spectrum necessitates the use of a wide array of acquisition tools relevant to the appropriate work awarded externally through full and open competition. Teaming among large companies, small businesses, and universities is highly encouraged for all procurement actions.

MAJOR CONTRACTS/AWARDS

NASA's Aeronautics programs award multiple smaller contracts which are generally less than $5 million. They are widely distributed across academia and industry.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Expert Review	Nov 2017	The 12-month review is a formal independent peer review. Experts from other Government agencies report on their assessment of technical and programmatic risk and/or program weaknesses.	The Panel provided favorable reviews to the projects. The Panel also gave constructive comments and recommendations.	Nov 2018

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Low Boom Flight Demonstrator	18.5	--	**88.3**	80.0	45.8	30.0	30.0
Integrated Aviation Systems Program	106.4	--	**100.9**	74.1	60.8	73.3	72.5
Total Budget	**125.0**	**--**	**189.2**	**154.1**	**106.6**	**103.3**	**102.5**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

The X-57 effort within the Flight Demonstrations and Capabilities Project exemplifies NASA collaboration with industry to develop, integrate, and demonstrate new technologies that will be widely applicable to future aircraft.

Flight research is critically important to create a bridge between fundamental research and technology transfer to the aviation community. Specifically, flight research advances technology readiness to the levels required for new technologies to be incorporated into future air vehicles and operational systems.

The goal of IASP is to demonstrate integrated concepts and technologies at a maturity level sufficient to enable their incorporation into operational systems at a level of risk that is acceptable to the aviation community. IASP focuses on the rigorous execution of highly complex flight tests and related experiments. These flight tests support all phases of ARMD research, not just the culmination of research activities. For technologies at low Technology Readiness Levels (TRLs), IASP flight research accelerates the development and/or determines the feasibility of those technologies. For more mature technologies, flight research will reduce risks and accelerate transition of those technologies to industry.

IASP also addresses the national challenge of routine access of Unmanned Aircraft Systems (UAS) into the National Airspace System (NAS) for civil use. Historically, UAS have supported military and security operations overseas, with training occurring primarily in the United States. However, significant interest is growing in civil uses, including commercial photography, aerial mapping, crop monitoring, advertising, communications, and broadcasting. The FAA is developing new policies, procedures, and approval processes to address demand for increasing civil UAS operations in the NAS. NASA will contribute flight-validated data and capabilities that reduce technical barriers related to the safety and operational challenges associated with enabling routine civil UAS access to the NAS.

IASP leads the Low Boom Flight Demonstrator (LBFD) project that will demonstrate quiet supersonic flight and open a new market to U.S. industry. Due to the high profile nature of this activity, a separate section dedicated to the LBFD follows the IASP program description. Also, IASP leads the Flight Demonstration and Capability (FDC) project which provides flight testing of technologies that will enable new aircraft configurations that significantly reduce fuel consumption, noise, and emission.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

- NASA collaborated with Aurora Flight Sciences to validate operational benefits and identify integration challenges associated with a new fuel-efficient aircraft configuration that incorporates Boundary Layer Ingestion technology (BLI) for reduced airframe drag. (Thrust 3/Flight Demonstrations and Capabilities [FDC])
- NASA conducted flight tests of the aerodynamics of a wing with an adaptive compliant trailing edge (ACTE) and a new landing gear fairing concept designed to reduce noise. To date, the flight tests have verified improved wing aerodynamics with the ACTE flap installed, and significant acoustic benefits through the use of landing gear noise reduction fairings; in addition, flight tests have enabled acoustic tool validation that will be instrumental in developing landing gear noise reduction treatments for future aircraft. (Thrust 3/FDC)
- IASP conducted multiple studies associated with advanced concept subsonic aircraft configurations. These studies were used to identify needed technology risk reduction activities to enable the next generation of subsonic aircraft. (Thrust 3/FDC)
- NASA continued the development of the X-57 Maxwell aircraft, a general aviation-scale aircraft to test a highly integrated distributed electric propulsion technology. NASA conducted tests of the battery system and conducted a critical design review for a new wing configuration. This demonstration is an important first step toward assessing the benefits and challenges of operating more electrified aircraft. (Thrust 4/FDC)
- The UAS Integration in the NAS (UAS-NAS) project closed out its Phase 1 effort to inform the development of Phase 1 Detect and Avoid Minimum Operational Performance Standards (MOPS) for the Radio Technical Commission for Aeronautics (RTCA) Special Committee 228. The project is working in conjunction with RTCA in developing standards necessary for UAS operations in the NAS. This MOPS will enable the FAA to develop Technical Standard Orders so that industry can build UAS flight hardware capable of safely integrating into the NAS. (Thrust 6/ UAS Integration in the NAS [UAS])
- The UAS-NAS project worked with the FAA to conduct a flight test of the Airborne Collision Avoidance System for Unmanned Aircraft (ACAS Xu). The ACAS is the replacement for the Traffic Collision Avoidance System (TCAS), and is designed specifically for UAS. The flight test provided benefits to the FAA and Industry to enable MOPS development as a necessary step to integrate UAS into the NAS. (Thrust 6/UAS)

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WORK IN PROGRESS IN FY 2018

- NASA is focusing on reducing community noise through the Landing Gear Noise Reduction (LGNR) effort that will demonstrate novel landing gear porous fairing and wheel cavity treatments. Flight testing is planned during spring 2018. In addition, the LGNR effort will extend the simulation-based airframe noise prediction methodology to the undercarriage and high-lift systems of large civil transports. The goal is to reduce the airframe component of community noise by 1.5 PLdB [Perceived Level (PL), decibels (dB)], or approximately 30 percent, with minimal impact on aircraft weight and performance, and to validate an advanced, physics-based methodology for the accurate prediction of airframe noise. (Thrust 3/FDC)

- Early in FY 2018, Phase 1 of the X-56, a remotely piloted subscale multi-utility technology testbed, research flights starts with the goal to prove enabling technology for designing aircraft with highly flexible, lightweight wings. The use of less structurally-rigid wings could be critical to future long-range, fuel-efficient airliners. This work is a cooperative effort by NASA's Advanced Air Transport Technology and Flight Demonstration Capabilities projects. Planned flights will be completed in mid-FY 2018. (Thrust 3/FDC)
- In FY 2018, IASP begins subsonic technology risk reduction tasks that were identified in FY 2017 as being the strongest contributors to the success of future flight demonstrations. Each effort has been awarded as a 12-month task to perform design and analysis activities required for risk reduction. IASP will conduct an assessment near the end of the fiscal year to determine which tasks will continue beyond the design/analysis phase into FY 2019. (Thrust 3/FDC)
- The X-57 Maxwell is conducting Mod II configuration flights where the aircraft will use electric motors and electrical storage and power distribution systems for all-electric flight. Following Mod II flights, the X-57 aircraft will be modified to the Mod III configuration; this includes integrating the newly designed, high-aspect ratio wing on the aircraft, and integrating the electric cruise motors onto the wing tips. The Mod III high aspect ratio wing will be delivered in FY 2018. Cruise efficiency gains are anticipated for the X-57 during the Mod III flights planned for FY 2019. (Thrust 4/FDC)
- NASA will provide the UAS No Chase Certificate of Authorization (NCC) Tech Briefing late in the second quarter of FY 2018. The goal is to leverage technologies that were developed in compliance with Phase 1 Detect and Avoid (DAA) MOPS to obtain FAA approval to fly the DAA system in the NAS with as few restrictions as possible. (Thrust 6/UAS)

KEY ACHIEVEMENTS PLANNED FOR FY 2019

- NASA will continue Landing Gear Noise Reduction work on a simulation-based airframe noise prediction methodology for the undercarriage and high-lift systems of large civil transports. Through simulations, this effort plans to demonstrate approximately a 30 percent reduction in the airframe component of community noise with minimal impact on aircraft weight and performance. Planned work on this advanced physics-based methodology for the accurate prediction of airframe noise will be completed in FY 2019. (Thrust 3/FDC)
- The X-57 Maxwell will conduct flights in the Mod III configuration which includes the integration of the new, high-aspect ratio wing. In addition, the Mod III configuration, while still utilizing all-electric systems, will feature mounting the electric motors for primary propulsion on the wing tips. As a result of these significant aircraft modifications, many of the integration challenges associated with installation of electrical and power distribution components will be addressed as the aircraft is prepared for flight. (Thrust 4/FDC)
- In FY 2019, the UAS-NAS project will complete flight testing of a low size, weight, and power airborne Detect and Avoid (DAA) surveillance capability. This flight demonstration is a key contributing event to Phase 2 DAA MOPS development in support of RTCA Special Committee 228 standards development for UAS. (Thrust 6/UAS)
- The UAS-NAS project will complete a flight test of a new control and non-payload communications radio in expected relevant operational environments. The test will demonstrate command and control capability in flight and contribute to Phase 2 standards development in support of RTCA Special Committee 228. (Thrust 6/UAS)

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Program Elements

UNMANNED AIRCRAFT SYSTEMS (UAS) INTEGRATION IN THE NATIONAL AIRSPACE SYSTEM (NAS)

In this project, NASA focuses on technologies to enable routine civil operations for UAS. This research aligns primarily with ARMD's Strategic Thrust 6: Assured Autonomy for Aviation Transformation, as well as Strategic Thrust 1: Safe, Efficient Growth in Global Operations. Since many of the current Federal aviation regulations support a pilot being in the aircraft, they are not directly applicable to UAS.

The UAS-NAS project leverages NASA expertise and capabilities to reduce technical barriers related to the safety and operational challenges associated with enabling routine UAS access to the NAS. The project is being conducted in two phases; Phase 1 began in May 2011 and ended in FY 2016. The primary focus of the Phase 1 work was development of research findings, through a series of demonstrations and simulations, to enable development of Detect and Avoid and Command and Control (C2) MOPS by RTCA for large UAS.

The Phase 2 effort is currently underway and will be completed in FY 2020. During Phase 2, the project focuses on the development of research findings, through a series of demonstrations and simulations, to enable Phase 2 DAA MOPS development to expand operations to other classes of UAS. In addition, C2 MOPS development will consider the use of Satellite Communications (SatCom) in multiple bands as a C2 Data Link to support UAS. For both DAA and C2, the project will validate technologies necessary for integrating UAS into the NAS.

FLIGHT DEMONSTRATIONS AND CAPABILITIES (FDC)

NASA's FDC project validates benefits associated with critical technologies through focused flight experiments. FDC demonstrates the feasibility and maturity of new technologies through flight tests, utilizing collaborative partnerships from across the aeronautical industry, and includes international partners as appropriate. These demonstrations typically address technologies that have proven their potential merit through ground based or subscale testing and require results from a realistic flight environment for validation of the expected benefits.

Through the integrated use of appropriate flight test capabilities and assets, the FDC project works to validate benefits associated with critical selected technologies. The flight experiments are campaigns focused on aggressive, success-oriented schedules utilizing the most appropriate set of assets available to accomplish the experimental objectives. While many of the technologies are at relatively high TRLs, the FDC project supports all phases of technology maturation.

The FDC project utilizes specific flight research and test capabilities residing within NASA, including the Dryden Aeronautical Test Range and Simulation and Flight Loads Laboratories at the AFRC, necessary to address and achieve the ARMD Strategic Plan, and program/project activities. The project also utilizes flight research and test capabilities across the U.S. aeronautical industry and international partners as appropriate.

Date	Significant Event
Mar 2018	UAS-NAS – Begin Flights for No-Chase Certificate of Waiver or Authorization (COA)
Sep 2019	UAS-NAS – Submit Consolidated Input for Detect and Avoid (DAA) MOPS Rev A to RTCA Special Committee for UAS
Aug 2020	UAS-NAS – Submit Consolidated Input for Command and Control (C2) Terrestrial Data Link MOPS to RTCA Special Committee for UAS
Sep 2020	UAS-NAS – Submit Consolidated Input for DAA MOPS Rev B to RTCA Special Committee for UAS
Nov 2017	FDC – Complete Flight Readiness Review (FRR) for X-56
Mar 2018	FDC – Complete Phase 1 Flights for X-56
Jun 2018	FDC – Complete Mod II Flight Test for X-57
Mar 2019	FDC – Complete Mod III Flight Test for X-57

Program Management & Commitments

Program Element	**Provider**
UAS Integration in the NAS	Provider: ARC, AFRC, GRC, LaRC Lead Center: AFRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): TBD
FDC	Provider: ARC, AFRC, GRC, LaRC Lead Center: AFRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): DoD, Air Force Research Laboratory, Lockheed Martin, Flexsys

Acquisition Strategy

NASA's IASP develops and further matures promising technologies to the integrated system level. This necessitates the use of a wide array of acquisition tools relevant to the appropriate work awarded externally through full and open competition. Teaming among large companies, small businesses, and universities is highly encouraged for all procurement actions.

MAJOR CONTRACTS/AWARDS

NASA's Aeronautics programs award multiple smaller contracts which are generally less than $5 million. However, contracts for the final design and construction of the LBFD will be substantially larger, depending on the scale and complexity of the plane. Smaller contracts are widely distributed across academia and industry. All design and build contracts will be widely competed through full and open competitions.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Expert Review	Oct 2017	The 12-month review is designed for the purpose of tracking and documenting the Project's progress made towards the Strategic Thrusts and Outcomes during the fiscal year.	The Review Panel acknowledged the Projects were on the right path and expressed appreciation for the good work done by all projects to remain relevant to its stakeholders. There were no findings.	Oct 2018

LOW BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**18.5**	**--**	**88.3**	**80.0**	**45.8**	**30.0**	**30.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

The LBFD concept successfully completed preliminary design and is on its way to being the world's first quiet supersonic aircraft.

PROJECT PURPOSE

Over the past decade, fundamental research and experimentation has demonstrated the possibility of supersonic flight with greatly reduced sonic boom noise. The LBFD will demonstrate these advancements in flight by utilizing a purpose-built experimental aircraft. It will provide validation of design tools and technologies applicable to low sonic boom aircraft and create a database of community response information supporting the development of a noise-based standard for supersonic overland flight.

The LBFD project will be executed in three phases. Phase 1 includes the LBFD aircraft development activities, starting from detailed design, continuing through fabrication, and concluding with functional checkouts and supersonic envelope expansion. In Phase 2, a NASA-led team will perform low-boom acoustic validation flights of the LBFD aircraft. These flights will characterize and evaluate the near-field, mid-field, far-field, and ground sonic boom signatures from the LBFD aircraft. Phase 2 will conclude with an initial community response overflight study to validate community test and survey designs and explore initial community acceptance of low-boom noise. For Phase 3, a NASA-led team will conduct low-boom community response overflight studies with multiple test campaigns using the LBFD aircraft over varied locations. The ultimate goal of Phase 3 will be to develop a low-boom community response database that will be provided to U.S. and international regulators in support of their development of a noise-based standard for supersonic overland flight.

Low Boom Flight Demonstrator

Formulation	Development	Operations

Explanation of Major Changes in FY 2019

None.

Project Preliminary Parameters

The LBFD project will design, manufacture, and perform flight validation of a research aircraft that creates a shaped sonic boom signature with a calculated loudness level of 75 PLdB [Perceived Level (PL), decibels (dB)] or less during supersonic cruise (Mach $\geq$ 1.4) flight. This loudness level is a considerable improvement over the Concorde's level of 105 PLdB. Although the aircraft will be smaller in size than future supersonic airliners, its sonic boom ground signature will be sufficiently well-understood to enable the design and construction of larger aircraft that will be able to comply with the noise-based standards that will be set by regulators. The LBFD aircraft will be capable of performing multiple supersonic overflights of a single community with passes that are nominally 50 miles in length, and up to 20 minutes apart on a single flight. The vehicle will be used to conduct low-boom community response studies with multiple overflight test campaigns in varied locations over the course of two years.

Achievements in FY 2017

NASA completed a successful Preliminary Design Review (PDR) of the LBFD aircraft concept which was awarded to Lockheed Martin in 2016. The PDR was a key input to the solicitation for the final design and build of the LBFD aircraft. PDR completion is also required prior to conducting KDP-C that is planned for September 2018.

Work in Progress in FY 2018

NASA will award a contract for the LBFD flight demonstrator aircraft to perform detailed design, build, test, and flight validation. This demonstrator will be used to collect the flight and community response data necessary to establish overland supersonic noise regulations. In addition, NASA will conduct the KDP-C for the LBFD aircraft. The successful completion of KDP-C will represent Authorization to Proceed to the execution phase of the project with validated plans for the cost and schedule of the LBFD project.

Key Achievements Planned for FY 2019

NASA will conduct a Critical Design Review (CDR) as the culminating event before the initiation final design activities for the LBFD aircraft. Following a successful CDR, the aircraft contractor will conduct aircraft build activities that include component fabrication and assembly, integration of Government Furnished Equipment (GFE), and final systems checkout in anticipation of NASA conducting a Flight Readiness Review late in FY 2020.

Formulation	Development	Operations

ESTIMATED PROJECT SCHEDULE

Milestone	FY 2019 PB Request	FY 2017 PB Request
Formulation Authorization	Sep 2016	Sep 2016
KDP-B	Aug 2016	Aug 2016
ASM	Nov 2016	Dec 2016
PDR	Jun 2017	Jun 2017
KDP-C	Sep 2018	Aug 2017
Delta PDR	Jun 2018	Jun 2018
CDR	Jun 2019	May 2019
KDP-D	Sep 2019	Aug 2019
FRR	Sep 2020	July 2020
First Flight	Jan 2021	Oct 2020

Formulation	Development	Operations

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

The LBFD project will officially baseline a cost and schedule in preparation for KDP C in FY 2018. NASA expects the current life cycle cost to encompass Fiscal Years from 2018 through 2025. The life cycle cost will include aircraft design and build, flight testing for aircraft envelope expansion, initial acoustic validation, community response testing through FY 2025. Since the Formulation Authorization Document (FAD) was prepared, NASA has better defined expected life cycle costs to include costs for the community response testing preparations and two additional years of community response flight testing. The project life cycle cost will be established in FY 2018 following award of the aircraft contract, completion of a Joint Confidence Level (JCL) assessment, and establishment of project reserve levels.

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or preliminary design review.

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
Aug 30, 2016	$390 to $395	First Flight	FY 2021

Project Management & Commitments

Element	Description	Provider Details	Change from Formulation Agreement
LBFD		Provider: ARC, AFRC, GRC, LaRC Lead Center: None Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): TBD	N/A

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
Sonic Boom Level is Not Acceptable for Community Overflight Research Given that achieving a fully shaped sonic boom ground signature in the 70-75PLdb range requires a complex and integrated design solution that is sensitive to OML changes, there is a possibility that the mission requirements related to ground signature loudness may not be achievable - resulting in an aircraft that may not be fully acceptable for community response studies.	NASA will ensure that all configuration assessments are accomplished with the latest and most mature aircraft configuration and periodically assess any updates to the aircraft configuration, such as the outer mold line, or performance characteristics.
Reduced Aircraft Performance Could Impact Mission Effectiveness Given the aircraft and propulsion system selection and integration complexity, there is a possibility of reduced aircraft performance resulting in loss of mission effectiveness, and leading to longer duration time to meet flight parameter(s), increased costs, and limitations of flight test points to standard-day conditions.	NASA will ensure that contractor has sufficient margin for aircraft weight growth with propulsion configuration, assess contractor aircraft performance and thrust predictions, both computationally and experimentally, over the aircraft flight envelope and perform a trade study on engine performance during demanding conditions.

Acquisition Strategy

The acquisition strategy for LBFD is to acquire through an industry partner the detailed design/build/test of the experimental low boom demonstrator aircraft. NASA will provide in-house support that will include in-flight and ground systems, instrumentation and operations, simulation, wind-tunnel testing, and safety and mission assurance. NASA will also supply aircraft components and systems as Government Furnished Equipment (GFE) whenever feasible and considered to add value to the development of the LBFD aircraft.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
LBFD Aircraft - Design, Build, and Initial Testing	TBD	TBD

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	LBFD Independent Review Board (IRB)	Jun 2017	PDR	Successfully Completed	Jun 2018
Performance	LBFD IRB	Jun 2018	Delta PDR	TBD	Jun 2019
Performance	LBFD IRB	Jun 2019	CDR	TBD	Sep 2020
Performance	LBFD IRB	Sep 2020	FRR	TBD	N/A

TRANSFORMATIVE AERO CONCEPTS PROGRAM

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	115.8	--	123.3	110.1	124.9	125.1	125.1

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Shown above is a supersonic aircraft model with the Outer Mold Lines (OML) identified. NASA's University Leadership Initiative is funding research to develop technologies to adapt the OML of supersonic aircraft geometry in real-time to mitigate sonic boom noise under changing flight conditions.

The Transformative Aero Concepts Program (TACP) cultivates multi-disciplinary, revolutionary concepts to enable aviation transformation. ARMD's strategic analysis has identified challenges in the global demand for mobility, significant energy and sustainability, and ongoing affordability issues, for which technology can be a key part of the solutions. TACP fosters innovative solutions to these problems, capitalizing on advancements in aeronautics and non-aeronautics sectors to create new opportunities in aviation. The ultimate goal of the program is to reduce or eliminate technical barriers and infuse internally- and externally-originated concepts into all six ARMD strategic research thrusts, creating innovation for the aviation system.

Using sharply focused activities, the program provides flexibility for innovators to explore technology feasibility and provide the knowledge base for radical transformation. The program solicits and encourages revolutionary concepts, creates the environment for researchers to become immersed in trying out new ideas, performs ground and small-scale flight tests, allows failures and learns from them, and drives rapid ideation into new concepts. TACP also places attention on computational and experimental tools that are critical for supporting technology development and enabling aviation transformation. Therefore, the program's investments are in never-done-before areas that can provide paradigm-shifting analysis and experimental capabilities. Further, the program addresses the technical barriers that need to be overcome in order to realize the potential for aviation transformation via applications of autonomy. TACP's new autonomous systems research activities address key technical barriers that will enable the use of autonomous systems in aviation. To increase the relevance of its work, TACP aggressively engages the traditional aeronautics community, as well as, non-traditional partners through public-private partnerships.

Across all ARMD programs, NASA researchers are developing innovative capabilities to advance the strategic thrusts and enable their outcomes. TACP challenges and supports the realization of the thrust outcomes with early stage innovations and with revolutionary technologies and methods.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

- NASA completed fabrication of an eight percent scale model of a wing-body junction of an aircraft that will be used in a major FY 2018 wind tunnel experiment. The Juncture Flow Experiment will take critical measurements of the turbulent airflow near the wing-body junction region of an aircraft. Data provided by the highly instrumented model will be used to validate NASA's new computational tools that better predict turbulent airflows and enable the design of future aircraft. (Cross Cutting/Transformational Tools and Technologies [TTT])
- NASA demonstrated a high-temperature material system for turbine engine components that enable a six percent reduction in fuel burn while meeting 2700 F use temperature and durability metrics. Higher temperature materials reduce the amount of cooling needed in engine turbines, improve fuel efficiency, lower operating cost, and reduce emissions. As part of this effort, NASA has been collaborating with a U.S. engine company to advance these high-temperature ceramic matrix composites (CMC) materials. The company plans to incorporate CMCs into the hot section of a new engine that will power the next generation of commercial airplanes. (Cross Cutting/TTT)
- NASA completed feasibility assessments for four Convergent Aeronautics Solutions (CAS) activities. The feasibility studies culminated the initial exploration of innovative new aeronautics concepts. All activities demonstrated feasibility in several key dimensions, but also revealed challenges that will need to be addressed prior to implementation. Contributions include a new toolset for designers of small unmanned aerial vehicles (UAV) and a concept that uses robotic construction of aircraft structures using strong, lightweight materials; another concept can significantly reduce ground testing time by allowing a new aircraft to "learn" its control system in flight similar to how a young bird learns to fly by jumping out of the nest. NASA is discussing a potential technology transition of this concept to a U.S. aerospace company. The final CAS activity demonstrated a concept that uses advanced sensors and models to create a "digital twin" that can predict the performance of a physical system over its lifecycle. (Cross Cutting/Convergent Aeronautics Solutions [CAS])
- NASA executed the first round of the competitive University Leadership Initiative awards under the University Innovation (UI) Project. Five University Awards have been granted:

  - Hyper-Spectral Communication, Networking and Air Traffic Management as Foundation for Safe and Efficient Future Flight;
  - Adaptive Aerostructures for Revolutionary Civil Supersonic Transportations;
  - Advanced Aerodynamic Design Center for Ultra-Efficient Commercial Vehicles;
  - Electric Propulsion: Challenges and Opportunities; and
  - Information Fusion for Real-Time National Air Transportation System Prognostics Under Uncertainty.

  These awards are the result of university leaders independently identifying and analyzing the technical barriers inherent in achieving ARMD’s strategic outcomes, and proposing set of multi-disciplinary solutions along with supporting activities to address those barriers. Total participants for all awards include twenty-one universities, seven companies, and one non-profit organization across twenty-one states. (Cross Cutting/University Innovation [UI])

WORK IN PROGRESS IN FY 2018

- NASA will complete the juncture flow validation experiment that examines the turbulent airflow around the wing-body junction of an aircraft. NASA will apply the results from this study and prior efforts to deliver critical turbulence models and numerical methods for separated flows that reduce the predictive error by 40 percent against standard test cases. Current fluid models have been unreliable in representing turbulent flow regions including separated flows. These limitations have prevented the broader use of numerical modeling for aircraft design, leading to higher costs and less than optimal designs. (Cross Cutting/TTT)
- NASA will continue working on additional computational tools that improve new air vehicle design such as Multidisciplinary Design, Analysis, and Optimization (MDAO) and Combustion Modeling. These tools will evaluate key enabling technologies for future subsonic aircraft configurations, advanced gas turbine engines, and/or hybrid electric propulsion systems that will achieve revolutionary levels of economic and environmental performance. (Cross Cutting/TTT)
- NASA's CAS Project initiates three new activities that support the Urban Air Mobility (UAM) domain. The first activity, Autonomy Teaming and TRAjectories for Complex Trusted Operational Reliability, will develop and measure trust inherent in autonomous systems. The second activity, Fit-2-Fly, will focus on conducting automated monitoring and inspection of UAVs. Finally, the third activity, Quantum Technologies for UAS, will apply quantum computing technologies to support secure UAV communications. (Cross Cutting/CAS)
- NASA will execute the second round of the competitive University Leadership Initiative (ULI) solicitations under the UI Project. The first annual ULI Technical Exchange Event begins in 2018. (Cross Cutting/UI)

KEY ACHIEVEMENTS PLANNED FOR FY 2019

- NASA will continue to develop multidisciplinary design optimization capabilities that will enable assessment of On-Demand Mobility (ODM) vehicle designs with tightly integrated propulsion-airframe systems that optimally account for competing requirements for performance, noise, and energy usage. (Cross Cutting/TTT)
- NASA will begin new CAS activities supporting multiple strategic thrusts. The following CAS activities will go to close-out/transition:

  - Lithium-Oxygen battery for NASA (LION),
  - Spanwise Adaptive Wing (SAW),
  - Fostering Ultra-Efficient, Low-Emitting Aviation Power (FUELEAP),
  - Compact Additively Manufactured Innovative Electric Motor (CAMIEM), and
  - Conformal Lightweight Antenna Systems for Aeronautical Communication Technologies (CLAS-ACT)

- NASA will solicit the third round of the competitive University Leadership Initiative proposals under the UI Project. These new proposals will address the technical barriers intrinsic in achieving ARMD's strategic outcomes. (Cross Cutting/UI)

Program Elements

CONVERGENT AERONAUTICS SOLUTIONS (CAS)

The CAS project performs rapid feasibility assessments of early-stage innovations that challenge existing technical approaches, create alternate paths to solutions, or enable new strategic outcomes. The project's focus is on merging traditional aeronautics disciplines with advancements driven by the non-aeronautics world to overcome barriers and enable new capabilities in commercial aviation. Internal research teams conduct initial feasibility studies, perform experiments, try out new ideas, identify failures, and try again. When a review determines whether the developed solutions have met their feasibility goals or identified potential for future aviation impact, ARMD considers the most promising capabilities for continued development by other programs or by direct transfer to the aviation community. In a dynamic environment of early stage innovation, NASA obtains significant value from the new knowledge gained and widely disseminates it among the aeronautics community at large.

TRANSFORMATIONAL TOOLS AND TECHNOLOGIES (TTT)

The TTT project advances state-of-the-art computational and experimental tools and technologies that are vital to aviation applications in the six strategic thrusts. The project develops new computer-based tools, models, and associated scientific knowledge that will provide first-of-a-kind capabilities to analyze, understand, and predict performance for a wide variety of aviation concepts. Applying these revolutionary tools will enable and accelerate NASA's research and the community's design and introduction of advanced concepts. Examples include the development and validation of new computational tools used to predict complex turbulent airflow around vehicles and within propulsion systems, ultimately leading to an improved ability to predict future vehicle performance in flight. The project also explores technologies that are broadly critical to advancing ARMD strategic outcomes, such as: understanding new types of strong and lightweight materials; innovative aircraft control techniques; and experimental methods. Such technologies will support and enable concept development and benefit assessment across multiple ARMD programs and disciplines.

In FY 2018, a new Autonomous Systems Sub-Project will start under TTT. This Sub-project will initially explore enabling capabilities and architectures that facilitate the introduction of autonomous airborne and ground-based systems.

UNIVERSITY INNOVATION (UI)

The UI project contains a portfolio of disruptive technologies and other entirely new concepts in order to meet the challenging goals established for each strategic thrust established by ARMD and support education of the next generation of engineers. The project utilizes NASA Research Announcement (NRA) solicitations where university-led teams are asked to assess the most critical technical challenges that must be solved to achieve the SIP strategic outcomes; and to propose independent, innovative research projects to solve those technical challenges. Universities develop their own success criteria, progress indicators, and technical approach. Solutions to these complex problems inherently involve high technical risk. Universities pursue multi-disciplinary approaches and incorporate partnerships with other universities, industry, and other U.S. entities. The competitively-selected research activities will open alternate avenues for accelerated progress by ARMD and the aerospace community toward the strategic outcomes, and will leverage new thinking and foster development of the next-generation aerospace workforce.

Program Schedule

Date	Significant Event
Oct 2017	TTT - New Autonomous Systems Sub-Project start
Dec 2017	CAS – Learn2Fly, Digital Twin, and Mission Adapt Digital Comp AeroTech (MADCAT) will begin close out/transition
Dec 2017	CAS – Autonomy Operating Systems for UAV begins Close Out/Transition
Mar 2018	CAS – High Voltage Hybrid Electric Prop and Multifunction Structure Energy Storage begins close out/transition
Mar 2018	TTT – Juncture Flow Experiment completes
May 2018	TTT – Revolutionary Computational Aerosciences completes technical challenge to reduce error of turbulent flows
Jun 2018	TTT – Physics-Based Turbulence Models and Simulations completes
Sep 2018	UI – Round 2 University Solicitations will be awarded
Jan 2019	CAS – Spanwise Adaptive Wing and Fostering Ultra-Efficient, Low-Emitting Aviation Power begins close out/transition
Jun 2019	CAS – Lithium-Oxygen battery for NASA, Compact Additively Manufactured Innovative Electric Motor and Conformal Lightweight Antenna Systems for Aeronautical communication Technologies begins close out/transition

Program Management & Commitments

Program Element	Provider
CAS	Provider: ARC, GRC, LaRC, AFRC Lead Center: GRC Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): JOBY Aviation, PCKrause & Associates, National Institute of Aerospace, Boeing, AFRL, ESAero, Tecnam MTProp, Launch Point, Cape Air, Straight Up Imaging, DoT Volpe, Moog Inc., IDEO, Idea Couture, Tecolote Research Inc., AFRL, WP AFB, Universities
TTT	Provider: ARC, GRC, LaRC, AFRC Lead Center: GRC Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): Boeing, Pratt & Whitney, Rolls Royce, Honda, UTRC, ESI, Blue Quartz Software, General Electric, FAA, AFRL, U.S. Air Force, U.S. Army, U.S. Navy, Defense Advanced Research Projects Agency (DARPA), Distributed Engine Controls Working Group Consortium, Honeywell, BAE Systems, UTC Aerospace Systems, Ohio Aerospace Institute, U.S. small businesses and universities

Program Element	Provider
UI	Provider: N/A Lead Center: HQ Performing Center(s): N/A Cost Share Partner(s): TBD

Acquisition Strategy

The research conducted through TACP activities will use a wide array of acquisition tools relevant to the research objectives including external solicitations through full and open competitions including challenges and prizes.

MAJOR CONTRACTS/AWARDS

NASA's Aeronautics programs award multiple smaller contracts, which are generally less than $5 million. They are widely distributed across academia and industry.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	ARMD Mission Program Directors	No previous review	Review of initial CAS project activities to determine whether they have met their goals, established initial feasibility, and identified potential for future aviation impact.	Expected result is the identification of the promising capabilities for further development by other ARMD programs or for direct transfer to the aviation community.	TBD
Performance	Expert Review	Nov 2017	The 12-month review is a formal independent peer review. Experts from other Government agencies report on their assessment of technical and programmatic risk and/or project weaknesses.	Received expert feedback on project improvement from the panel members. Determined that the project(s) made satisfactory progress in meeting technical challenges and met all annual performance indicators.	Nov 2018

EDUCATION

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**100.0**	**99.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

EDUCATION

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**100.0**	**99.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Change from FY 2018			**-99.3**				
Percentage change from FY 2018			**0.0%**				

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Interns from JSC pose with astronaut Nick Hague before Extravehicular Activity (EVA) training in the Neutral Buoyancy Laboratory.

The FY 2019 Budget proposes the termination of NASA's traditional education portfolio of domestic assistance awards (grants and cooperative agreements) that are fully funded in the year of the award or annually funded with a performance period of three to five years.

NASA will continue to support other education activities, such as internships and fellowships, within the Mission Directorates. For example, the Science Mission Directorate will continue its Science Activation Program.

A new focused functional office at NASA headquarters will be accountable for strategic direction and coordination of the agency's STEM engagement efforts. NASA will focus on creating unique opportunities for students to contribute to NASA's work in exploration and discovery; build a diverse future STEM workforce by engaging students in authentic learning experiences with NASA's people, content and facilities; and strengthen public understanding by enabling powerful connections to NASA's mission and work. This functional office, along with the Office of Communications, will be jointly accountable for working collaboratively toward successful achievement of the common vision, mission and goals on behalf of the agency and will be funded out of Agency Management and Operations.

EXPLANATION OF MAJOR CHANGES IN FY 2019

No funding is requested for Space Grant, EPSCoR and MUREP. NASA proposes to use unobligated balances previously appropriated under this heading to support the termination of these activities, including but not limited to, ongoing administration, oversight, monitoring, and funding of grants previously awarded by the Office of Education. Moving forward, it is expected that a new focused functional office funded by Agency Management and Operations will oversee agency-wide coordination of STEM engagement efforts. Please refer to the Agency Management and Operations section of the budget justification for more details.

WORK IN PROGRESS IN FY 2018

National Space Grant College and Fellowship Program (Space Grant)

Based on the availability of funding, Space Grant consortia will receive a one-year funding extension to the existing three-year award for all 52 Space Grant consortia members. Space Grant awards consist of scholarships, fellowships, or internships in support of higher education, research infrastructure, precollege, and informal education. Space Grant consortia will also support flight project activities led by student teams.

Established Program to Stimulate Competitive Research (EPSCoR)

- Make new research awards based on availability of funding.

Minority University Research and Education Program (MUREP)

Pending availability of funding:

- Provide final year of funding for the five-year MUREP Institutional Research Opportunity awards.
- Support final year of funding for the Educator Professional Development Collaborative five-year awards.
- Support NASA Community College Aerospace Scholars awards.
- Support fellowships, scholarships, and internships.
- Support MUREP Aerospace Academy awards.

STEM Education and Accountability Project (SEAP)

Based on the availability of funding:

- Provide final year of funding for the previously awarded internal STEM education awards, currently being executed at all NASA Centers.
- Support a limited number of competitively-selected informal education awards to NASA's Visitor Centers and the Nation's museums, science centers and planetariums to enhance NASA STEM (science, technology, engineering, and mathematics) education activities, including exhibits, events, and materials.

PLANS FOR FY 2019

NASA will implement an orderly shutdown of the OE programs and projects. This effort will be guided by these overarching goals: Minimize negative impact to awardees And perform closeout in a cost-effective and efficient manner.

SAFETY, SECURITY, AND MISSION SERVICES

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Center Management and Operations	1986.5	--	**1949.6**	1945.4	1939.8	1934.1	1928.5
Agency Management and Operations	782.1	--	**800.1**	799.4	798.8	798.2	797.6
Total Budget	**2768.6**	**2749.8**	**2749.7**	**2744.8**	**2738.6**	**2732.3**	**2726.1**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

SAFETY, SECURITY, AND MISSION SERVICES

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Center Management and Operations	1986.5	--	**1949.6**	1945.4	1939.8	1934.1	1928.5
Agency Management and Operations	782.1	--	**800.1**	799.4	798.8	798.2	797.6
Total Budget	**2768.6**	**2749.8**	**2749.7**	**2744.8**	**2738.6**	**2732.3**	**2726.1**
Change from FY 2018			**-0.1**				
Percentage change from FY 2018			**0.0%**				

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

NASA workforce and facilities provide the tools and services needed to safely conduct its mission.

Safety, Security, and Mission Services (SSMS) manages the administration of the Agency; operates and maintains NASA centers and facilities in ten states and the District of Columbia (Headquarters); and provides oversight that reduces risk to life and mission for all NASA programs.

SSMS maintains both institutional and program capabilities across the Agency. Strategically, these capabilities meet workforce and infrastructure requirements necessary to enable NASA's mission.

Institutional capabilities ensure that critical Agency operations are effective, efficient, and meet statutory, regulatory, and fiduciary responsibilities. Program capabilities ensure that competencies, technical skills and capabilities, and assets are readily available to meet programmatic requirements; mission and research endeavors are technically and scientifically sound; and Agency practices are consistently safe and reliable at NASA Centers.

These capabilities enable missions to accomplish Agency strategic goals and objectives. In addition to related processes, both are testament to the complexity of the support needed to successfully and safely implement and complete requisite missions. Following are several examples:

- Engineering, systems engineering, and safety and mission assurance capabilities support technical activities;
- Information Technology (IT), infrastructure, and security capabilities support the productivity of NASA scientists and engineers;

- Human capital management, finance, procurement, occupational health and safety, equal employment opportunity and diversity provide needed resources throughout the Agency, and small business programs contribute to the strategic and operational planning and management that ensure resources are available when needed; and
- International and interagency relations, legislative and intergovernmental affairs, and strategic communications facilitate communications with a broad range of internal and external communities.

EXPLANATION OF MAJOR CHANGES IN FY 2019

NASA is increasing Agency IT Services to strengthen cybersecurity capabilities and safeguard critical systems and data. NASA's FY 2019 request includes investments in critical IT infrastructure and enterprise solutions. Center Management and Operations (CMO) funding increases reliability-centered maintenance and condition-based monitoring activities at centers to provide more efficient and effective systems maintenance.

ACHIEVEMENTS IN FY 2017

NASA is working to instill a culture of innovation in its workforce by recognizing and rewarding innovative performance; engaging and connecting the workforce to make it easy for employees to collaborate, network, and innovate; and, creating an environment in which leaders view developing innovative employees as a productive and vital use of their time. SSMS activities provide the facilities, tools, and services needed to conduct NASA’s missions safely and effectively. Most notably, in 2017, NASA:

- Pursued over the course of several years a disciplined approach to improving the Agency’s Operating Model. In May 2017, NASA’s Executive Council took the next step in a series of initiatives to become more efficient and effective as an Agency. The Mission Support Future Architecture Program (MAP) developed an overall implementation plan and management structure and approach to execute a phased enterprise architecture for mission support services. Since May, the MAP team laid the framework for the program, defined the program’s objectives and kicked off the first phase of projects.
- Successfully implemented effective energy conservation and cost saving projects by reducing energy and water use, and improving operations. Glenn Research Center (GRC) utilized an Energy Savings Performance Contract through the Department of Energy's Federal Energy Management Program that allows federal agencies to partner with utility companies. Energy cost savings funds the project; thereby, reducing the need for federal funding. The GRC Energy Conservation Measures project saved $928K in energy savings; and $325K in operations and maintenance costs.
- Named the "Best Place to Work" for the sixth year in a row among large agencies in the Federal Government. Employee satisfaction and commitment scores continued to improve with NASA maintaining focus on connecting people to each other and the mission, building model supervisors, and recognizing and rewarding innovative performance.
- Received a “Clean” financial audit opinion for the seventh consecutive year; and for the third consecutive year received the Associate of Government Accounts Certificate of Excellence in Accountability Reporting (CEAR).

- A first for NASA, the Independent Verification and Validation (IV&V) program is accredited as a third party assessor for the Federal Risk and Authorization Management Program (FedRAMP). IV&V is certified to assist cloud service providers and government agencies in complying with FedRAMP requirements. NASA is one of only two federal agencies with this certification throughout the Federal Government.
- In 2017, 123,000 technical standards products were downloaded from the NASA Standards website; and, made available to all NASA civil servant employees and NASA badged contractors. The website is updated regularly and enhances the promotion of best industry practices and provides electronic notification of changes for registered standards to help users verify and identify current documents. The website provides single-point, instantaneous access to the world's largest collection of continuously updated engineering and technical reference documents from over 400 standard developing bodies and publishers; plus, engineering tools. The NASA Standards web link is https://standards.nasa.gov/.
- The Office of the Chief Medical Officer (OCHMO), in collaboration with NASA's Commercial Crew Program (CCP), completed a critical task of updating NASA's Health Stabilization Plan (HSP) for Commercial Crew transport missions to the International Space Station (ISS). ISS crew health-related standards address all mission phases and target physiological and behavioral and performance systems at risk from exposure to the space environment.
- NASA continued efforts to modernize cybersecurity services and governance; and, implemented enterprise security tools to reduce cybersecurity risks. The Office of Chief Information Officer (OCIO) deployed Phase I of the Department of Homeland Security’s (DHS’s) Continuous Diagnostics and Mitigation (CDM) Program on NASA's corporate network. Phase 1 will be completed by deploying tools on mission networks in FY 2018.

WORK IN PROGRESS IN FY 2018

SSMS continues its’ crosscutting support of the Agency’s aeronautics and space activities, using innovative approaches in providing the required programmatic, business, and administrative capabilities. Key activities underway include:

- Replacement of the end-of-life land mobile radio system at NASA's Marshall Space Flight Center (MSFC). This system supports over 600 NASA MSFC radio users and approximately 1200 other federal government users that are Redstone Arsenal tenants (DoD, ATF, FBI, and Missile Defense Agency).
- Extensive reinforcement of network and IT infrastructure cybersecurity with the deployment of tools designed to secure the external network perimeter and monitor the network for malicious attacks. The Agency is enhancing cybersecurity capabilities of its Security Operation Center (SOC); and, IT Security Program. This includes improvements to incident response, insider threat management, continuity of operations, enterprise cyber security architecture, cybersecurity risk management, and cybersecurity workforce development.
- NASA's continued support for the Mission Support Future Architecture Program (MAP). In early FY 2018, NASA's Mission Support Council (MSC) voted to proceed with MAP implementation. Phase 1 projects are the Office of Human Capital Management (OHCM), the Office of Chief Financial Officer (OCFO), and the Office of Legislative and Intergovernmental Affairs (OLIA)). These Phase 1 projects will complete the first Key Decision Point (KDP) to the MSC in FY 2018.

- Strategic Capability Asset (SCA) - Arc Jets continue development of Thermal Protection Systems for the Orion Spacecraft at NASA's Ames Research Center (ARC). Orion's thermal protection system is one of the most critical parts of the spacecraft and is responsible for protecting it and the future astronauts conducting space missions. Engineers developing Orion's thermal protection system continue to improve the spacecraft's heat shield design and manufacturing process; and are enhancing the overall system in advance of the spacecraft's next mission.
- The Office of Safety and Mission Assurance (OSMA) will engage in the technology demonstration of the Space Debris Sensor (SDS) that will take place on the International Space Station (ISS). The SDS is a large area impact sensor for measurements of Micrometeoroids and Orbital Debris (MMOD) in the sub-millimeter to millimeter size regime including particle size and material density. Increased understanding of the orbital debris environment will assist NASA in determining appropriate mission requirements to guard against orbital debris and meteoroid impacts that could lead to mission failure.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

In FY 2019, SSMS programs will continue to balance the risks across center and Agency services and activities to provide a safe, reliable infrastructure to conduct NASA's aeronautics and space activities. SSMS programs will support:

- CMO facility maintenance and operations, including utility and custodial support of more than 5,000 buildings and other structures containing 47.3 million gross square feet of building area valued at $39 billion. Centers will continue to increase reliability-centered maintenance and condition-based monitoring activities to provide more efficient and effective systems maintenance.
- OSMA development of assurance capabilities to mitigate risks associated with rapidly advancing industry capabilities in additive manufacturing; commercial-grade EEE parts; model-based systems engineering; and software design practices. These capabilities provide technical and cost saving opportunities for future NASA missions.
- IV&V expert software analysis on NASA's safety and mission critical software to help assure safety and mission success by identifying software problems as early as possible, minimize the cost of rework, and support key milestone decisions.
- Collaborative efforts between OSMA, the Office of the Chief Engineer (OCE), and OCHMO to strengthen the Agency's Technical Authority capability. The offices will work together, conducting safety reviews and independent technical assessments of NASA's missions (including ISS, Commercial Crew, Orion/SLS, Webb, robotic missions, and Space Technology investments).
- OCHMO continued implementation of all Health and Medical Technical Authority (HMTA) technical standards for research and technology (R&T) and human space flight (HSF) programs and projects; and those related to occupational and / or environmental health requirements that are not established by the U.S. Department of Labor Occupational Safety Health Administration (OSHA) or the Environmental Protection Agency (EPA). OCHMO will continue to work as the health and medical technical authority on all human missions, including those to lunar and Mars surfaces.

- Agency Management (AM) Center integration of onsite Electronic Physical Access Systems (EPACS) equipment into the EPACS Public Key Infrastructure (PKI) agency suite; and completion of the EPACS re-architecture initiative.
- AITS continued efforts to ensure that NASA networks are safeguarded from unauthorized and potentially malicious connections and access. The OCIO plans to deploy its Enterprise Internal Border Network Access Control (EIB-NAC) project. These EIB-NAC cybersecurity tools will enable the Agency to effectively manage user network access by placing users in network zones commensurate with cybersecurity policies. OCIO will also establish an agency-level SOC responsible for delivering and managing all enterprise cybersecurity services. The SOC will implement tools to monitor and inspect encrypted web traffic and safeguard NASA data from potential exfiltration by attackers. This initiative will consolidate redundant cybersecurity services across NASA Centers.
- SCA's planned testing of the Space Power Facility (SPF) at NASA's GRC. SPF is home to the world’s largest and most powerful space environment simulation facilities. The Orion spacecraft will undergo thermal vacuum and acoustics and vibrations testing at the facility.

Themes

CENTER MANAGEMENT AND OPERATIONS

CMO provides ongoing management, operations, and maintenance of NASA Centers and component facilities throughout the United States. Centers provide the resources needed (skilled staff, specialized infrastructure, etc.) for Centers to accomplish strategic goals and objectives.

AGENCY MANAGEMENT AND OPERATIONS

Agency Management and Operations (AMO) provides management and oversight of NASA missions and facilitates the performance of Mission Support activities throughout the Agency. AMO activities ensure that core services are readily available across the Agency to perform mission related roles and responsibilities.

CENTER MANAGEMENT AND OPERATIONS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Center Institutional Capabilities	1534.9	--	**1513.6**	1509.4	1503.8	1498.1	1492.5
Center Programmatic Capabilities	451.6	--	**436.0**	436.0	436.0	436.0	436.0
Total Budget	**1986.5**	**--**	**1949.6**	**1945.4**	**1939.8**	**1934.1**	**1928.5**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Center facility maintenance includes roof repairs such as this new roofing system installed on Building 5 at NASA Glenn Research Center.

NASA’s CMO budget funds ongoing management, operations, and maintenance at Centers and component facilities in nine states. CMO includes two major activities: Center Institutional Capabilities and Center Programmatic Capabilities.

Missions rely on these program and institutional capabilities to provide the skilled staff and specialized infrastructure required to accomplish their objectives.

Center institutional capabilities provide the facilities, staff, and administrative support for effective and efficient NASA Center operations. These capabilities enable NASA Centers and missions to meet its statutory, regulatory, and fiduciary responsibilities.

Program capabilities support scientific and engineering activities at the Centers to reduce program risks. These program capabilities ensure that technical skills and assets are ready and available to meet program and project milestones; that missions and research are technically and scientifically sound; and that Center practices are safe and reliable.

EXPLANATION OF MAJOR CHANGES IN FY 2019

Increases facility maintenance ($57.6M) activities at all Centers to provide more efficient and effective systems maintenance. Reduces risk and future operating costs by investing in facilities and proactive maintenance initiatives. Continues modest investments in conditioned-based maintenance (CBM) including installing sensors and equipment to reduce scheduled maintenance inspections and allow real time monitoring. Retro-commissions existing facilities to ensure they are operating optimally to improve efficiency and performance.

CENTER MANAGEMENT AND OPERATIONS

ACHIEVEMENTS IN FY 2017

NASA continued to improve operations, enabling the Agency to meet mission requirements while conduct day-to-day technical and business operations more effectively. For example:

- NASA Centers conducted a series of inspections, reviews, studies, and analysis that served to further enhance and promote NASA's Safety Culture: Annual Facility Safety Inspections, Annual Laboratory Safety Inspections, Facilities Drawing Reviews, Integration and Test Safety Operations, Construction Safety Inspections, Preconstruction Meetings/Reviews, Facility Adjacency Studies, Cryogenic Safety Analyses, Emergency Response, and Safety Program Analyses.
- In 2017, NASA Centers continued to expand on the use of CBM. CBM promotes maintaining an asset upon decreasing performance or when a failure is impending; instead of at an arbitrary time regardless of condition. Special attention was paid to remote sensing and monitoring of assets around the center to cut maintenance costs and extend overall operational lifetime of assets. Currently, LaRC co-leads the Agency Business Services Assessment (BSA) team for CBM; and, GRC installed CBM equipment within three of its buildings.
- NASA Centers enthusiastically facilitated the support of public outreach and awareness of NASA activities: Goddard Space Flight Center (GSFC) supported the return of commercial resupply missions to the International Space Station (ISS) from the Wallops Flight Facility (WFF); and, the media outreach for completion of the optical and science segment of the James Webb Space Telescope (JWST).
- Layered high-pressure gas storage vessels are critical to meeting technical mission requirements, but many are more than 50 years old and require assessment to assure their continued safe operations. To reduce risk of jeopardizing these technical capabilities, Marshall Space Flight Center (MSFC) initiated repairs on layered vessel V0256 (a recommendation in the Layered Vessel Risk Mitigation Plan). Reactivation of this layered vessel reduces the Pressure System risk for personnel by 56% and for property by over 30%, from the FY 2014 Baseline Service Level (BSL).

WORK IN PROGRESS IN FY 2018

In FY 2018, Centers are providing the essential day-to-day technical and business operations required to conduct NASA’s aeronautics and space mission activities. Activities encompass the services, tools, and equipment required to complete essential tasks, protect and maintain the security and integrity of information and assets, and ensure that personnel work under safe and healthy conditions. Efforts underway include:

- Dedicate Human Capital resources for the implementation of Business Services Assessment (BSA) Decisions in the areas of Strategic Workforce Planning, Recruitment and Hiring, Classification and Staffing, Early Career Hires, Supervisors, Talent Development, Organizational Development, and Inter/Intra-Center Collaboration. Support BSA activities in order to realize potential benefits, including but not limited to, more efficient operations, cost savings, greater collaboration and integration, and divestment/reinvestment of resources.
- Continue to develop condition-based maintenance related to the Businesses Services Assessment and Reliability Centered Maintenance Program. NASA is planning to implement additional

functionality in CBM environment to include metrics and scorecards (provides a framework for the development of dashboards, key performance indicators and scorecards) and operator rounds (enables field monitoring of equipment and processes). The Agency will continue the evaluation of additional CBM technologies such as Infrared Radiation (IR) Thermography and In-line Oil Analysis.

- Initiate a project at Armstrong Flight Research Center (AFRC) to address digitally archiving the nearly six million pages of historical research program and project documentation. This effort will result in a searchable database which will make the information available to more researchers as well as protecting this valuable historical research.
- Make critical improvements to the Integration & Test Complex infrastructure at GSFC. Expand clean room space to handle growing detector work/house new technological advance equipment, flip-chip bonder. Upgrade the Near Field Range to test antennas from 500 GHz-750 GHz to support earth science and planetary science missions. Upgrade the Anechoic Chamber Capabilities.
- Replace the end-of-life land mobile radio system at MSFC. This system supports over 600 NASA MSFC radio users and approximately 1200 other federal government users that are Redstone Arsenal tenants (DoD, ATF, FBI, and Missile Defense Agency).

KEY ACHIEVEMENTS PLANNED FOR FY 2019

Centers will provide the services, tools, and equipment to complete essential tasks, protect, and maintain the security and integrity of information and assets, and ensure that personnel work under safe and healthy conditions. In FY 2019, CMO will support:

- Facility maintenance and operations, including utility and custodial support of more than 5,000 buildings and other structures containing 47.3 million gross square feet of building area valued at $39 billion. Centers will continue to increase reliability-centered maintenance and condition-based monitoring activities to provide more efficient and effective systems maintenance.
- IT services and capabilities for video, voice, and desktop support at Centers to include efforts to reduce duplication of software licenses;
- Cybersecurity resources to more effectively and efficiently address vulnerabilities across the agency;
- Institutional operational safety support to protect personnel and assets, aviation safety, emergency preparedness, nuclear safety, construction safety, and other safety services;
- Physical security, fire protection and response, emergency management, export control, and other basic and specialized protective services;
- Compliance with environmental regulations, executive orders, and related requirements to protect human health and the environment;
- Human resource management; including: recruitment, hiring, workforce planning, training, and performance management. In FY 2019, NASA will continue rightsizing its workforce with a reduction of 110 FTE relative to the 2018 Request. NASA will continue to explore opportunities across the Agency to find efficiencies in workforce productivity. The Agency will apply the valued civil service workforce to priority mission work, adjusting the mix of skills where appropriate. Centers will explore cross-mission opportunities for employees whenever possible,

use the range of tools available to reshape the workforce, and continue to identify, recruit, and retain a multi-generational workforce of employees who possess skills critical to the Agency.
- Occupational and environmental health and medical support, such as industrial hygiene, health physics, hearing conservation, and licensed and credentialed medical personnel and facilities to meet specialized mission requirements;
- Personal property management, transportation management, mail management, and other logistical support;
- Duplicating and printing support, video production, audio/visual services, and publications and graphics (includes specialized support for the production and archiving of scientific and technical information);
- Senior leadership and management of the Centers, executive staff and administrative support, student programs, and developmental assignments;
- Routine public affairs activities, dissemination of information about NASA programs and projects to the general public, and responses to public inquiries;
- Administration and management of Center financial operations;
- Acquisition and contract management capabilities and practices supporting 41,000 procurement actions each year;
- Engineering assessment and safety oversight pertaining to the technical readiness and execution of NASA programs and projects; and
- Analysis, design, research, test services, and fabrication capabilities to enable efficient implementation of the programs and projects.

Program Elements

CENTER INSTITUTIONAL CAPABILITIES

Center Institutional Capabilities encompasses a diverse set of activities essential for safe and effective operations. These activities provide the ongoing operations of NASA Centers and major component facilities and ensure a safe, healthy, and environmentally responsible workplace. Included are essential operations such as Center security, environmental management and safety services, and facility maintenance and operations. To support the Agency's Center-based workforce, Center Institutional Capabilities provide utilities, IT, legal, occupational health, equal employment opportunity, and human resources services. This capability manages and sustains Center staff, facilities, and operations.

CENTER PROGRAMMATIC CAPABILITIES

NASA's Center Programmatic Capabilities supports the Agency's scientific and engineering activities by providing engineering assessment and safety oversight pertaining to the technical readiness and execution of NASA programs and projects. It also sustains NASA's analysis, design, research, test services, and fabrication capabilities to enable efficient implementation of the programs and projects conducted at the Centers.

CENTER MANAGEMENT AND OPERATIONS

NASA's Center Programmatic Capabilities supports the Agency's scientific and engineering activities by providing engineering assessment and safety oversight pertaining to the technical readiness and execution of NASA programs and projects. It also sustains NASA's analysis, design, research, test services, and fabrication capabilities to enable efficient implementation of the programs and projects conducted at the Centers.

Center Programmatic Capabilities provide a key component of NASA's overall system of checks and balances. The engineering, safety and mission assurance, and health and medical organizations at the Centers provide, support, and oversee the technical work and provide formally delegated Engineering ($131 million) and Safety and Mission Assurance Technical Authorities ($48 million) at NASA Centers. These technical authorities provide independent oversight and review of programs and projects in support of safety and mission success. Cognizant technical authorities formally review and concur on technical and operational matters involving safety and mission success risk. These technical authorities concur based on the technical merits of each case and agreement that the risks are acceptable. This assures that NASA conducts its mission activities safely in accordance with accepted standards of professional practice and applicable NASA requirements.

AGENCY MANAGEMENT AND OPERATIONS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Agency Management	359.2	--	**359.5**	358.8	358.2	357.6	357.0
Safety and Mission Success	176.3	--	**175.8**	175.8	175.8	175.8	175.8
Agency IT Services (AITS)	219.8	--	**238.1**	238.1	238.1	238.1	238.1
Strategic Capabilities Asset Program	26.8	--	**26.7**	26.7	26.7	26.7	26.7
Total Budget	**782.1**	**--**	**800.1**	**799.4**	**798.8**	**798.2**	**797.6**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

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Independent Assessment allows NASA to independently review and assess technical and mission risks. Shown here is the GOES-R weather satellite launch.

The AMO budget provides management and oversight of Agency missions and performance of NASA-wide mission support activities. AMO activities at NASA Headquarters (HQ) ensure that core services are ready and available, Agency-wide, for performing mission roles and responsibilities and that Agency operations are effective and efficient and meet statutory, regulatory, and fiduciary requirements.

NASA HQ develops policy and guidance for the Centers and provides strategic planning and leadership; and, establishes Agency-wide requirements and capabilities that improve collaboration, efficiency, and effectiveness. Agency management leverages resources and capabilities to meet mission needs, eliminate excess capacity, and scale assets accordingly.

AMO provides for policy-setting, executive management, direction for all corporate functions, and supports the operational costs of the Headquarters installation. The AMO theme consists of four programs: Agency Management, Safety and Mission Success (SMS), Agency IT Services (AITS), and Strategic Capabilities Assets (SCA).

AGENCY MANAGEMENT AND OPERATIONS

EXPLANATION OF MAJOR CHANGES IN FY 2019

NASA is increasing Agency IT Services to strengthen cybersecurity capabilities and safeguard critical systems and data. NASA's FY 2019 request includes investments in critical IT infrastructure and enterprise solutions. Funding will support modernizing Agency systems, increased automation, and optimized delivery of enterprise-wide IT service solutions.

ACHIEVEMENTS IN FY 2017

NASA maintained its position as the top large agency in the 2017 rankings as the Best Place to Work in the Federal Government, improving our employee satisfaction and commitment score by focusing on three key priority areas: connecting people to each other and the mission; building model supervisors; and recognizing and rewarding innovative performance.

The Agency implemented a new governance model for IT applications designed to promote application portfolio management and achieve improvements across multiple portfolio health factors including cybersecurity, redundancy, interoperability, cost of ownership, and sustainability. NASA modernized cybersecurity services and governance and implemented enterprise security tools to reduce cybersecurity risks. The Agency implemented a “Personal Identity Verification (PIV) Mandatory” project to deploy security tools that enforce PIV smartcard authentication by employees accessing NASA computers.

SMS conducted 11 formal, stringent Safety and Mission Success Reviews and seven Safety and Mission Success Assessments. These reviews are the culmination of the identification and mitigation of potential safety and mission assurance risks for launches and high criticality events. The NASA Safety Center conducted 18 audits, assessments, and reviews at eight separate NASA Centers and component facilities in FY 2017.

NASA continued efforts during FY 2017 to gain efficiencies through Business Service Assessments (BSA). NASA implemented changes in order to gain efficiencies in the areas of IT, Procurement, and Human Capital. Activities also included developing integrated implementation strategies in order to execute Agency-approved process improvements in the areas of Budget, Facilities, and Education and Outreach.

WORK IN PROGRESS IN FY 2018

In FY 2018, the Independent Verification and Validation (IV&V) Program is currently providing software expertise to 19 projects, including 16 NASA missions, Commercial Crew Program, two multi-agency missions, and across eight NASA Centers.

The NASA Engineering and Safety Center (NESC) plans to conduct over 50 independent assessments of NASA’s highest risk challenges maintaining prioritization on the ISS, Commercial Crew, Orion/Space Launch System (SLS), James Webb Space Telescope (Webb), and Space Technology.

NASA is reinforcing its network and IT infrastructure cybersecurity with the deployment of tools designed to secure the external network perimeter and monitor for malicious attacks. The Agency improvement of SOC capabilities and deployment of tools to monitor encrypted traffic for intrusion will help improve NASA's cybersecurity posture and compliance with statutory requirements and government-wide cybersecurity policies.

AGENCY MANAGEMENT AND OPERATIONS

NASA's current learning management and training solution will be updated to a cloud-based solution as the current system is at end-of-life. NASA's Communications Program will complete the Agency-wide transition to the improved mission-wide area backbone and decommission legacy services as a cost reduction measure. NASA will also replace aging mission voice systems and migrate from obsolete time-division multiple technology to internet-protocol.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

NASA will continue the implementation of BSA decisions, establishing a more effective, efficient and transformative Mission Support operating model to meet current and future Agency objectives.

OCIO will establish an agency-level Security Services Office responsible for delivering and managing all enterprise cybersecurity services. The SOC will implement tools to monitor and inspect encrypted web traffic and safeguard NASA data from potential exfiltration by attackers. The OCIO plans to standup a formal cybersecurity risk management program that will integrate cybersecurity risk management processes across the agency. The Centers Enterprise Physical Access Management Systems will be consolidated into a single enterprise solution.

IT investments will enable NASA to improve cybersecurity, reduce costs and increase efficiencies by modernizing Agency systems, increasing automation, delivering affordable enterprise-wide IT service solutions, strengthening technical capabilities, and achieving cost avoidances and savings through strategic investments.

Collaborative efforts between the Office of Safety and Mission Assurance (OSMA), Office of Chief Engineer (OCE), and OCHMO will continue to strengthen the Agency's Technical Authority capability. The offices will continue to work together, conducting safety reviews and independent technical assessments of NASA's missions, including ISS, Commercial Crew, Orion/SLS, Webb, robotic missions, and Space Technology investments.

Program Elements

AGENCY MANAGEMENT

Agency Management provides functional and administrative management oversight for the Agency and operational support for NASA Headquarters. Agency Management governance and oversight activities include finance, protective services, general counsel, public affairs, external relations, legislative affairs, training, human capital management, procurement, real property and infrastructure, budget management, systems support, internal controls, diversity, equal opportunity, independent program and cost evaluation, and small business programs.

SAFETY AND MISSION SUCCESS

SMS programs protect the health and safety of the NASA workforce and improve the probability of safety and mission success for NASA's programs, projects, and operations. SMS includes NASA Headquarters programs, providing technical excellence, mission assurance, and technical authority. This includes the work managed by OSMA, IV&V, OCE, and OCHMO.

AGENCY MANAGEMENT AND OPERATIONS

AGENCY INFORMATION TECHNOLOGY SERVICES

The AITS program provides critical technology capabilities and is dedicated to ensuring every mission can achieve success within NASA's complex environment. The AITS mission improves management and security of IT systems while improving the efficiency, collaboration capabilities, and streamlined service delivery and visibility into IT for the entire Agency.

STRATEGIC CAPABILITIES ASSETS PROGRAM

SCA ensures the essential Agency test facilities are in a state of readiness, maintains the skilled workforce, and performs essential preventative maintenance to keep these facilities available to meet program requirements. Core capabilities supported within SCA are thermal vacuum chambers, simulators, and the Arc Jet Facility.

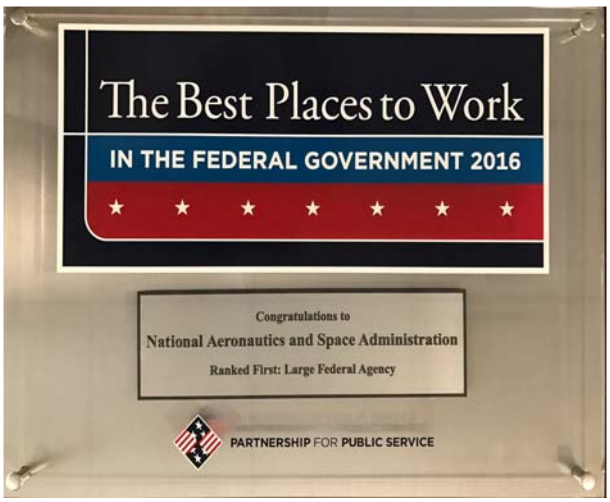
AGENCY MANAGEMENT

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	359.2	--	359.5	358.8	358.2	357.6	357.0

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



NASA Headquarters, located in Washington, DC provides overall planning, policy direction, and corporate management for The Agency. NASA maintains its ranking as the top large agency as the Best Place to Work in the Federal Government in 2017.

Agency Management provides functional and administrative management oversight for the Agency and operational support for NASA Headquarters. Agency Management supports the activities necessary to conduct business in the Federal sector and provides the capability to respond to legislation and other mandates. The Agency Management program supports over 35 discrete operations and mission support activities.

Agency Management provides policies, controls, and oversight across a range of functional and administrative management service areas. This includes governance and oversight activities such as finance, protective services, general counsel, public affairs, international and interagency relations, legislative affairs, training, human capital management, procurement, communications, real property and infrastructure, budget management, systems support, internal controls, diversity, equal opportunity and small business programs. The Agency Management program supports operational activities of Headquarters similar to a Center. These activities include building lease costs, facility operations costs (such as physical security, maintenance, logistics, IT hardware, and software costs), automated business systems implementation, and operations costs (such as internal control initiatives related to transparency and accountability in government).

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

AGENCY MANAGEMENT

ACHIEVEMENTS IN FY 2017

NASA continued to lead the federal government as the top large agency in the 2017 rankings as the Best Place to Work in the Federal Government. Employee satisfaction and commitment scores continued to improve with NASA maintaining focus on connecting people to each other and the mission, building model supervisors, and recognizing and rewarding innovative performance.

For the seventh consecutive year, the Agency received a “Clean” financial audit opinion and for the third year in a row NASA received the Associate of Government Accounts Certificate of Excellence in Accountability Reporting (CEAR). The Office of the Chief Financial Officer also provided leadership on the 2018 NASA Strategic Plan, the first strategic plan developed under Government Performance and Results Act Modernization Act (GPRAMA), including new requirements such as Strategic Reviews and Enterprise Risk Management and lead NASA implementation of the DATA act. They also led development and delivery of a high-quality Agency Reform Plan, incorporating ongoing Agency reform activities and building on the “Unbounded Ideas” developed with the Presidential Appointments Team (PAT), in coordination with numerous other offices across NASA Headquarters.

The Office of Small Business Programs (OSBP) established the NASA Industry Forum (NIF), an Agency-wide endeavor to share Center-level information that is of concern to both NASA, its industry partners and share best practices. During FY 2017, NASA continued its Regional Outreach initiative to partner with regional Chambers of Commerce and Procurement Training Assistance Centers (PTACs) to assist contractors that have never had any prior NASA contracts.

During 2017, the NASA Protective Services Training Academy (NPSTA) achieved Federal Law Enforcement Training Accreditation for its Federal Arrest Authority training program. NASA's participation in the accreditation process ensures public confidence and the integrity, professionalism and accountability of NASA security forces. The National Security Systems (NSS) Team also met the Internal Operating Capability (IOC) and the Fully Operational Capability (FOC) requirements outlined under the umbrella of the Committee on National Security Systems Directive on Protecting National Security Systems from Insider Threat.

NASA Headquarters heightened its Continuity of Operations (COOP) capabilities to provide for the continued management and operations of the Agency in the event that Agency management is not able to remain in or operate from the National Capital Region. Headquarters participated in the 2017 FEMA Eagle Horizon exercise by testing the Devolution Emergency Response Group’s ability to continue NASA’s essential functions during any type of threat or emergency in the event that the primary operating facility is incapacitated and personnel are unavailable or incapable of activating or deploying to the normal continuity facility.

Agency Management examples of BSA successes:

- Cost avoidance by the Office of Chief Information Officer (OCIO) realized as a result of a BSA decision to consolidate various SharePoint collaboration environments. The OICO has restructured and streamlined IT governance boards to effectively engage Agency stakeholders and is implementing a major network upgrade that will enable a single network across NASA.
- The Office of Procurement is implementing a new single task ordering tool that will replace 10 existing tools across the Agency. They have also implemented the use of alternate contracting approaches to assist Centers and expedite the process, while maintaining the process integrity.

AGENCY MANAGEMENT

They have developed a web-based contract repository for strategic sourcing and category management.

- The Office of Human Capital Management (OHCM) is implementing a new hiring system to replace the current outdated system to modernize hiring and provide managers more flexibility in selections. OHCM has also adjusted performance plans for supervisors to limit technical duties and ensure that supervisory duties are at least 50 percent.
- The Office of Strategic Infrastructure (OSI) - Facilities is developing an Agency Master plan to document the facilities required to accomplish NASA's mission and goals for the next 20 years.

WORK IN PROGRESS IN FY 2018

NASA Headquarters is enhancing its space management capabilities through the introduction of Building Information Modeling (BIM). The BIM toolset helps automate clash detection of elements such as electrical conduit or ductwork that run into a beam. By modeling all of these things first, clashes are discovered early, and costly on-site clashes can be reduced. The model also ensures a perfect fit of elements that are manufactured off-site. The BIM Model links to facility management Software (Space Planning and Maintenance & Energy Modeling) reducing overall building life cycle costs.

NASA's Office of Protective Services (OPS) continues to provide threat protection across the Agency. OPS will deploy the NASA Visitor Management System to replace standalone visitor systems which will enhance agency wide visitor security and tracking. NASA will also receive FBI Automated Fingerprint Identification System (AFIS) capability which will allow NASA to submit fingerprints directly to the FBI and the PerSec Case Initiative system will track security clearance for NASA employees and contractors. OPS will also complete the Personal Identity Verification Card Issuer Audit required by Homeland Security which allows NASA to continue to print credentials and the Identity Management Modernization project.

NASA's Office of Small Business Programs (OSBP) is improving the Agency performance in small business subcategories by identifying, increasing, and promoting small business prime contracting opportunities. NASA has set Center prime goals for FY 2018 based on current and anticipated requirements as well as on continuous improvement.

The Mission Support Directorate will continue crosscutting support of the Agency's activities, using innovative approaches to provide the required programmatic, business, and administrative capabilities. Key activities underway include:

- Gaining additional efficiencies through our BSA activities. This includes performing comprehensive reviews, developing implementation plans and institutionalizing previously made business service decisions. Options and recommendations are in development based on the assessment of Technical Authority. NASA has initiated comprehensive reviews of the Protective Services and Logistics activities.
- The Office of Communications will identify opportunities and leverage public engagement capabilities across organizations and Centers and ensure effective collaboration among Center communications and/or public engagement offices to establish strong partnerships.

AGENCY MANAGEMENT

KEY ACHIEVEMENTS PLANNED FOR FY 2019

Beginning in FY 2019, Phase 1 MAP projects will begin actual transition to new operating architectures with budget and management responsibilities aligned. Phase 1 MAP projects include the Office of Human Capital Management, the Office of the Chief Financial Officer, and the Office of Legislative Affairs. Phase 2 Mission Support functions will also be identified and begin the process.

In FY 2019, the Mission Support Directorate (MSD) will continue to balance the risks across Center and Agency services and activities to provide a safe, reliable infrastructure to conduct NASA's aeronautics and space activities. MSD will:

- Implement long-term changes identified through the BSAs to optimize services, and maintain a minimum set of capabilities to meet mission needs;
- The Enterprise Protection Program (EPP) was developed to increase coordination on critical infrastructure protection. The EPP will establish a working group focused on coordination of work on the protection of this infrastructure in response to a NASA IG recommendation.
- Implement improvements from the Education and Outreach BSA, including better coordination by the headquarters education office that reports to the Agency Administrator; and
- Conclude BSA as an "initiative" after completing assessments on Protective Services and Logistics. Upon completion, NASA will have assessed the major mission support functional areas that comprise over 70% of CMO funding, including Information Technology, Procurement, Human Capital, Budget and PP&C, Facilities, Education and Outreach, Technical Authority, Protective Services, and Logistics. Mission Support Directorate has developed a "mini-BSA" process for smaller functional areas to leverage. Our future strategy continues to optimize mission support operations across NASA.

Program Elements

HEADQUARTERS OPERATIONS

Headquarters Operations manages and sustains the Headquarters employees and contractors, facilities, and operations required for program and institutional execution. Areas include:

- Facility operations support, including physical security, custodial, and maintenance services; equipment; expendable supplies; mail services; motor pool operations; logistics services; and emergency preparedness;
- Human resources staffing; employee payroll and benefits processing; retirement services; employee training; employee occupational health, fitness, and medical services; and grants awards processing; and
- Headquarters operations, including support provided by Goddard Space Flight Center for accounting and procurement operations; configuration maintenance; automated business and administrative systems; contract close-out services; and payments to the NASA Shared Services Center for grants management.

AGENCY MANAGEMENT

MISSION SUPPORT

The Agency Management budget also provides for functional leadership of administrative and mission support activities at Headquarters and Centers performing this diverse set of activities on behalf of the Agency.

Mission Support activities include:

- Execution and management of the Agency's financial and budget processes and systems. This includes overseeing strategic planning, budget and financial management and accountability practices while providing timely, accurate, and reliable information, and enhancing internal controls;
- Leadership and management of NASA protective services operations. This includes policy formulation; oversight, coordination and management of protective services operations, including security, fire, emergency management, and emergency preparedness; support for Agency counterintelligence and counter-terrorism activities; implementation of the ICAM and other security systems, including communications; COOP; and national intelligence community services;
- Technical expertise and oversight of Agency infrastructure and management systems for: aircraft, environmental, real property, logistics, and strategic capabilities programs; and
- Leadership and management of the Agency's human capital resources and Equal Employment Offices. These offices engage the Agency in proactive equal opportunity and diversity and inclusion initiatives, workforce development and alternate dispute resolution services and complaint investigations.

SAFETY AND MISSION SUCCESS

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Safety and Mission Assurance	49.6	--	**49.5**	49.5	49.5	49.5	49.5
Chief Engineer	83.4	--	**83.0**	83.0	83.0	83.0	83.0
Chief Health and Medical Officer	4.2	--	**4.4**	4.4	4.4	4.4	4.4
Independent Verification and Validation	39.1	--	**38.9**	38.9	38.9	38.9	38.9
Total Budget	**176.3**	**--**	**175.8**	**175.8**	**175.8**	**175.8**	**175.8**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Carlie Zumwalt from Langley Research Center (LaRC) inspects a supersonic disk-gap-band (DGB) parachute model in the Transonic Dynamics Tunnel as part of the NASA Engineering and Safety Center's (NESC) Subscale Low Density Supersonic Parachute Wind-Tunnel Test. NASA has used the DGB parachute design on all US missions to Mars, since the 1976 Viking Project, to decelerate robotic payloads in the planet's thin atmosphere.

SMS programs protect the health and safety of the NASA workforce and improve the likelihood that the Agency's programs, projects, and operations will be completed safely and successfully. SMS includes programs that provide technical excellence, mission assurance, and technical authority. It also includes work managed by the Office of Mission Assurance (OSMA), including the NASA Safety Center (NESC) and the Independent Verification and Validation (IV&V); the Office of the Chief Engineer (OCE) including the NASA Engineering and Safety Center (NESC); and the Office of the Chief Medical Officer (OCHMO).

The elements of SMS reflect the recommendations outlined in many studies and by advisory boards and panels. These programs directly support NASA's core values and serve to improve the probability of safety and mission success of NASA's programs, projects, and operations, while protecting the health and safety of NASA's workforce.

SMS develops policy and procedural requirements. This program results in recommendations to the Administrator, mission directorates, Center Directors, and program managers who ultimately are responsible for the safety and mission success of all NASA activities; and, the safety and health of the workforce. SMS resources provide the foundation for NASA's system of checks and balances, enabling the effective application of the strategic management framework and the technical authorities defined in NASA's Strategic Management and Governance Handbook. SMS funds provide training and maintain a competent technical workforce within the disciplines of system engineering, including system safety, reliability and quality, as well as space medicine.

SMS resources are essential for evaluating the implications on safety and mission success, including the health and medical aspects of new requirements and departures from existing requirements. With this funding, discipline experts analyze the criticality of the associated risks and evaluate the risks acceptability through an established process of independent reviews and assessments. The information and advice from these experts provide critical data required by the technical authorities to develop authoritative decisions related to the application of requirements on programs and projects.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

In FY 2017, SMS conducted 12 formal, stringent Safety and Mission Success Reviews and 5 Safety and Mission Success Assessments. These reviews are the culmination of the identification and mitigation of all potential SMA problems for launches and high criticality events. Substantive participation in Directorate Program Management Council (DPMC), Flight Planning Boards, Key Decision Point (KDP) reviews, and selected lower level reviews and assessments collectively enable effective governance and successful mission implementation.

OSMA updated eight Agency directives and four NASA standards. Significant changes encompassed critical updates on Human Rating, Risk Management, and Planetary Protection.

The NASA Safety Center conducted 18 audits, assessments, and reviews at seven separate NASA Centers and component facilities in FY 2017. The audit and assessment program categorizes findings that provide NASA installations with opportunities to improve the safety and quality of their operations and activities. NASA programs and projects at these locations are reviewed to optimize and enhance their safety and quality assurance accomplishments. During the fiscal year, the NASA Safety Center also documented 243 findings that included potential systemic issues, critical concerns, non-compliances, observations, commendations, and best practices.

The NASA Engineering and Safety Center (NESC) completed 19 independent assessments and satisfied 16 requests for technical support touching all of NASA's Mission Directorates. These assessments furthered NASA goals and contributed directly to the Agency mission through better informed decision-making and an overall reduction of risk. Results included a comprehensive assessment of the ESD integrated vehicle dynamic test plan to an analysis of Micrometeoroid and Orbital Debris (MMOD) induced flight failures and their implications for MMOD risk.

OCHMO updated several major Agency-level health and medical directives/standards; and, continued collaborative efforts with NASA's Office of Safety and Mission Assurance (OSMA), Health Physics Society, American Industrial Hygiene Association, and US Outdoor Laser Safety communities such as

SAFETY AND MISSION SUCCESS

SAE G10T and ANSI Z136.1. The OCHMO conducted occupational health reviews at five NASA Centers last year to ensure that established requirements, sound principles, and recommended best practices are used to accomplish NASA's occupational health objectives.

As the Health and Medical Technical Authority (HMTA) for the Agency, OCHMO has ensured that risks to humans are communicated to, and addressed by, appropriate decision makers before spaceflight. With the passage of HR 6076 (To Research, Evaluate, Assess, and Treat Astronauts Act aka "TREAT"), OCHMO has led the Agency effort to oversee a NASA study to determine the best method to implement astronaut healthcare.

OCHMO performed Human System Integration (HSI) compliance assessment for both Commercial Crew Transportation Capability (CCtCap) providers. Further, OCHMO developed a process to enable Human-In-the-Loop testing at Commercial Crew Transportation Capability (CCtCap) provider facilities. The OCHMO also published one new Agency policy directive as it pertains to Human Genetics Testing and updated a number of Agency policy standards and directives that ensure the health and well-being of the NASA workforce. OCHMO and the Commercial Crew Program (CCP) completed the update of the Health Stabilization Plan for Commercial Crew transport missions to ISS.

WORK IN PROGRESS IN FY 2018

OSMA continues to assure the safety of all NASA activities through the development, implementation, and oversight of Agency-wide safety, reliability, maintainability, and quality assurance policies and procedures. Of particular note is the technology demonstration of the Space Debris Sensor (SDS) that will take place on the International Space Station (ISS). The SDS is a large area impact sensor for in situ measurements of Micrometeoroids and Orbital Debris (MMOD) in the sub-millimeter to millimeter size regime including particle size and material density. These MMOD particles are too small to be detected by ground-based radars and optical telescopes, but still large enough to be a serious threat to human space activities and robotic missions in the Low Earth Orbit (LEO) region. A successful SDS demonstration on the ISS will enable the OSMA to seek future mission opportunities to deploy the sensor to collect direct orbital debris measurement data at high LEO altitudes (600-1000 km), a region where NASA regularly operates more than 15 missions. Increased understanding of the orbital debris environment there will assist NASA in determining appropriate mission requirements to guard against orbital debris and meteoroid impacts that could lead to mission failure.

IV&V is currently providing software expertise to 19 projects, including 16 NASA missions, Commercial Crew Program, two multi-agency missions, and across eight NASA Centers.

OCE, including the NESC, continues to support the achievement of the Agency's major priorities. Through the Agency technical reviews, OCE maintains Technical Authority caucuses to ensure full integrity and to ensure all dissenting and divergent opinions are fully heard and appropriately considered. The NESC plans to conduct over 50 independent assessments of NASA's highest risk challenges maintaining prioritization on the ISS, Commercial Crew, Orion/SLS, Webb, and Space Technology. Several activities underway in FY 2017 will be continued into FY 2018 including independent EDL modeling and simulation for the CCP and integrated ascent trajectory and separation analyses for the ESD SLS and Orion programs. In addition, work will continue on development of shell buckling knockdown factors for composite shells. OCE continues to be an active participant in the Agency's Technical Capability Leadership efforts and provides leadership for a number of discipline-related assessments.

SAFETY AND MISSION SUCCESS

OCHMO will continue to establish health, medical, human performance policies, requirements, and standards for all human space flight programs and projects; technical standards levied on or supported by research and technology programs and projects; and NASA-unique occupational and environmental health requirements that are not mandated by Occupational Safety and Health Administration (OSHA) or the Environmental Protection Agency (EPA).

OCHMO with continue toward ensuring that the Health and Medical Technical Authority (HMTA) is robust and serve as an independent path for analysis; and assuring that health and medical standards are appropriately and efficiently administered by NASA programs. OCHMO will continue to lead the Multilateral Medical Policy Board in addressing and resolving several critical issues dealing with crew health and medical operations support to the International Space Station (ISS) operations.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

At the core of the Agency's preventive approach to achieve safety, health, and mission success are:

- Routine on-site inspections and regular self-audits to ensure compliance with mandatory regulations, Agency policies, industry standards, and best practices;
- Robust knowledge management and communities of practice that capture and inculcate lessons learned into future missions;
- Multi-faceted training and development programs to ensure the SMS workforce has the necessary skills and capabilities;
- Comprehensive review processes to identify and mitigate risks and to analyze and understand failures when they occur. This strategy and practice will continue to provide a systematic approach to support mission success; and
- Independent tests and analyses for resolving critical technical issues faced by NASA programs and projects.

OSMA will develop assurance capabilities to mitigate risks associated with rapidly advancing industry capabilities in additive manufacturing; commercial-grade EEE parts; model-based systems engineering; and software design practices. These capabilities provide technical and cost saving opportunities for future NASA missions. In collaboration with industry and academia, OSMA intends to reinvigorate its program of benchmarking, developmental, and test activities, to identify and establish suitable assurance tools, methods, and standards that address the greatest SMA challenges. Increases in the out-year budgets will significantly enhance these efforts.

In FY 2019, IV&V plans to continue to provide expert software analysis on NASA's safety and mission critical software. This is designed to help assure safety and mission success by identifying software problems as early as possible, minimize the cost of rework, and support key milestone decisions. Further, the IV&V Program plans to continue to enhance its technical capabilities and focus on continuous improvement and best value.

SAFETY AND MISSION SUCCESS

OCE will continue to engage in collaborative efforts between OSMA, OCE, and OCHMO to strengthen the Agency's Technical Authority capability. The offices will work together, conducting safety reviews and independent technical assessments of NASA's missions (including ISS, Commercial Crew, Orion/SLS, Webb, robotic missions, and Space Technology investments).

OCHMO will continue to implement the HMTA as it pertains to all technical standards for research and technology (R&T) and human space flight (HSF) programs and projects; and, those related to occupational and / or environmental health requirements that are not established by OSHA or EPA. OCHMO will continue to work as the health and medical technical authority on all human missions, including those to lunar and Mars surfaces, and to assure the safety and health of NASA's entire workforce – on earth and beyond.

Program Elements

SAFETY AND MISSION ASSURANCE

SMA establishes and maintains an acceptable level of technical excellence and competence in safety, reliability, maintainability, and quality engineering within the Agency. SMA assures that the risk presented by the lack of either safety requirements or compliance with safety requirements is analyzed, assessed, communicated, and used for proper decision-making and risk acceptance by the appropriate organizational leader.

Fundamental to these responsibilities are the definition and execution of a robust and well-understood methodology and process for the application of the safety, reliability, and quality in defining the level of risk. SMA conducts a schedule of reviews and assessments that focus on the life cycle decision milestones for crucial NASA programs and projects as well as for safety, reliability, and quality processes. Embodied in this program is a structured development of methodology and investigation into system attributes that improve the probability of mission success.

The NASA Safety Center is an important component of SMA and is responsible for consolidating Agency-wide SMA efforts in four key areas: SMA technical excellence, knowledge management, audits and assessments, and mishap investigation support.

INDEPENDENT VERIFICATION AND VALIDATION

Software, as an asset, on NASA's missions is extremely critical. IV&V is a proven means of making sure critical software works properly. IV&V can identify software problems as early as possible; and, help minimize the cost of software development and potential rework.

The IV&V Program provides software expertise, services, and resources necessary to improve the likelihood for safety and mission success of programs, projects, and operations. The Program analyzes mission software independently, on NASA's most critical software systems, to assure safety and mission success of these systems.

SAFETY AND MISSION SUCCESS

IV&V applies state of the art analytical methods and techniques. This is complemented with use of effective software engineering tools and best practices. Collectively, IV&V evaluates the correctness and quality of critical and complex software systems throughout the project's system development life cycle.

In support of independent evaluations of software related approaches and processes, IV&V provides resources and software expertise to other SMA elements. The Program also supports the sustainment of software technical excellence within the Safety Mission Assurance (SMA) community, sustainment of software domain knowledge within the SMA organization, and formulation of software development improvement recommendations to the Agency.

IV&V performs independent testing of critical system software to increase the likelihood of discovering severely difficult problems in mission software early within the development lifecycle. Critical system software problems can surface because of multiple complex interactions, under specific environmental and operational conditions, and under unique software configurations. IV&V Program's independent test capability enables: Advanced testing and simulations of NASA's mission and safety critical software; Testing and evaluation of robotics and intelligent systems; Capability development within the systems engineering disciplines; and Training and education for workforce and students.

OFFICE OF THE CHIEF ENGINEER

OCE ensures that NASA's development efforts and mission operations are planned and conducted on a sound engineering basis with proper controls and management of technical risks. As the Engineering Technical Authority, the OCE implements checks and balances among key organizations to ensure that decisions have the benefit of different points of view and are not made in isolation. OCE establishes and maintains program/project management and engineering policy and technical standards, creating the foundation for excellence of the Agency's program and project management and engineering workforce, system-engineering methodology, and the Agency's system of engineering standards. The office manages the NESC, which is responsible for enabling rapid, cross-Agency response to mission critical engineering, and safety issues at NASA and for improving the state of practice in critical engineering disciplines. Established in FY 2003 in response to the recommendations of the Space Shuttle Columbia Accident Investigation Board, the NESC performs independent testing, analysis, and assessments of NASA's high-risk projects to ensure safety and mission success. SMS funding provides for the core NESC organization of senior engineering experts from across the Agency, including the Technical Fellows and technical discipline teams. Technical Fellows, in turn, manage the capabilities of their respective technical disciplines. As an Agency-wide resource with a reporting path that is independent of the Mission Directorates and independently funded from OCE, the NESC helps ensure safety and objective technical results for NASA. The OCE is also responsible for the implementation of Discipline-level Capability Leadership through the NASA Technical Fellows.

OCE sponsors the Academy of Program/Project and Engineering Leadership to develop program and project management and systems engineering skills. This academy provides a formal professional development curriculum designed to address four career levels from recent college graduate to executive. The OCE professional development programs directly support project teams in the field through workshops, coaching, interactions with technical experts, training, forums, and publications. The office enables technical collaboration and information sharing through the NASA Engineering Network. The NASA Engineering Network is an Agency-wide capability providing single point access to technical standards, communities of practice, and lessons learned in a secure operating environment. The engineering standards program maintains compliance with OMB Circular A-119, “Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities,” and offers a centralized source of required engineering standards for NASA programs and projects at one-fourth the cost of a decentralized approach.

OFFICE OF THE CHIEF HEALTH AND MEDICAL OFFICER

OCHMO promulgates Agency health and medical policy, standards, and requirements, to support the medical technical capabilities of the Agency. It assures the physical and mental health and well-being of the NASA workforce, and assures the safe and ethical conduct of NASA-sponsored human and animal research. The office monitors the implementation of health and medical related requirements and standards in all developmental human space flight programs through designated discipline experts at NASA Centers.

The office provides oversight of medical and health related activities in operational human space flight through Center-based discipline experts and clinical boards. Annual certified continuing medical education activities and flight surgeon education support ongoing medical and health discipline professionalism and licensure. To maintain clinical currency, OCHMO sponsors university-based physician training programs. NASA’s biomedical research programs, in support of human space flight, are guided by NASA-developed health and medical standards.

AGENCY IT SERVICES (AITS)

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
IT Management	15.9	--	**18.3**	18.3	18.3	18.3	18.3
Enterprise IT	203.9	--	**219.8**	219.8	219.8	219.8	219.8
Total Budget	**219.8**	**--**	**238.1**	**238.1**	**238.1**	**238.1**	**238.1**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

NASA Mission Control Center room at Johnson Space Center. The mission networks are managed by Agency IT Services.

NASA's AITS program provides information technologies and services to support the delivery of NASA's missions, safely and securely. AITS enables the management of information needed to fulfill NASA's mission. The program simultaneously works to secure a vast array of data and complex IT infrastructure, from computers aboard the International Space Station (ISS) to mobile devices used Agency-wide. AITS ensures access to scientific data and promotes participation in NASA's activities.

The Office of the Chief Information Officer (OCIO) provides leadership, planning, policy direction, and oversight for the management of AITS; and ensures that IT investments align to the NASA Strategic Plan and NASA IT Strategic Plan. The AITS strategy is documented in the NASA Information Technology (IT) Strategic Plan, through which NASA seeks to manage IT as a strategic resource to unleash the power of data throughout the Agency. The NASA IT Strategic Plan sets the goals and objectives for partnering with customers to deliver excellence, capitalize on data and innovation, safeguard National data and assets, maximize business value through optimization and unleash the power of NASA's data.

EXPLANATION OF MAJOR CHANGES IN FY 2019

NASA is increasing Agency IT Services to strengthen cybersecurity capabilities and safeguard systems and data. NASA's FY 2019 request includes investments in critical IT infrastructure and enterprise solutions. Funding will support modernizing Agency systems, increased automation, and optimized delivery of enterprise-wide IT service solutions.

AGENCY IT SERVICES (AITS)

ACHIEVEMENTS IN FY 2017

IT GOVERNANCE AND OVERSIGHT

The OCIO strengthened the management of NASA's IT portfolio. Partnering with Mission and Centers, the OCIO executed a series of in-depth reviews. Results included a better understanding of NASA's IT footprint; improved security of IT assets; and an enhanced ability to meet external reporting requirements. The initiative enhanced NASA's ability to accurately identify and track IT within Missions.

OCIO executed the second annual IT Capital Investment Review (ITCIR). The Agency reviewed IT portfolio data in the ITCIR from enterprise, mission, and Center perspectives by the NASA's Information Technology Council (ITC). In compliance with FITARA requirements, the Agency's Chief Financial Officer (CFO) and Chief Information Officer (CIO) certified the IT Portfolio investment data prior to submission to the Office of Management and Budget (OMB).

The Agency implemented a new governance model for IT applications designed to promote application portfolio management and achieve improvements across multiple portfolio health factors (including cybersecurity, redundancy, interoperability, cost of ownership, and sustainability).

SAFEGUARDING NASA'S DATA AND IT ASSETS

NASA modernized cybersecurity services and governance and implemented enterprise security tools to reduce cybersecurity risks. The OCIO deployed automated asset inventory tools provided through Phase I of the Department of Homeland Security's (DHS's) Continuous Diagnostics and Mitigation (CDM) Program. CDM Phase 1 tools were deployed on NASA's corporate network. Phase 1 will be completed by deploying tools on mission networks in FY 2018.

To integrate and manage CDM-generated data, the Agency deployed its Risk Information Security Compliance System (RISCS). RISCS provides NASA with a centralized toolset to integrate the Agency's cybersecurity data sources into a single reporting system.

The Agency implemented a "Personal Identity Verification (PIV) Mandatory" project to deploy security tools that enforce PIV smartcard authentication by employees accessing NASA computers. An alternate PIV credential (the Agency Smart Badge) was made available to those ineligible for a PIV card. The new credential allows for authentication, encryption, digital signature and physical access.

SERVICE DELIVERY

The Agency completed the IT BSA, which evaluated NASA's IT business and mission support services, assessed the health of IT services, and identified opportunities for optimization. The resulting decisions and implementation plan provided requirements for improving mission-enabling IT services within six NASA IT programs, including Information Management, Applications, End User Services, Computing Services, Communications, and IT Security.

OCIO altered several existing initiatives during the formulation of the Information Management (IM) Program, which shifted focus from a compliance-based to an information-centric, data-driven process that enhanced insights and analytics capabilities. The Scientific and Technical Information (STI) document

AGENCY IT SERVICES (AITS)

repository increased by over 5,000 new technical records, including formal and informal NASA research and development findings, approved conference papers, scientific and technical journal articles, and final contract reports.

A machine learning algorithm was developed to classify official email records for NASA leadership and automatically categorized the records for archival purposes. A machine learning algorithm was also developed, tested, and trained to predict metadata tags for NASA-specific publications and documents. NASA designed an information architecture framework to model agency data by type, source, use, and location.

The End User Services (EUS) Program completed refreshes for over 17,000 computers, 4,600 mobile devices, and 2,400 printers, delivering current technology. NASA implemented PIV authentication on Apple, Inc. and PC machines and improved patching and updates for users' computers.

The Agency completed a major cloud prototyping effort designed to demonstrate the viability of commercial cloud services to support Earth Science Programs. The successful prototype led to an additional effort with significantly increased scope and objectives.

The Cloud Access Security Broker (CASB) tool was implemented to provide visibility into the use of Software as a Service (SaaS). The CASB tool will provide the information needed to enable governance for the rapidly growing reliance on commercial SaaS. NASA authorized operation for three commercial SaaS products and closed three data centers in 2017, consolidating the data center environment from 26 to 23.

NASA implemented two-factor authentication for enterprise business applications. A Contract Management Transformation (CMT) project was completed that enabled retirement of a legacy enterprise contract writing application and decommission of several Center applications.

WORK IN PROGRESS IN FY 2018

IT GOVERNANCE AND OVERSIGHT

In FY 2018, the OCIO continues to review strategic IT priorities and investments toward maturation, as well as establish a sustainable framework and structure for NASA IT portfolio analysis. This includes a full integration of the IT data collection and analysis process within the Agency's budget formulation process; and, scheduling in collaboration with the OCFO and Mission Directorates.

OCIO's Enterprise Architecture (EA) program continues to perform assessments of IT Program capabilities to identify gaps. EA establishes vision, goals and objectives for cross-cutting architectures which allows for greater integration between the IT portfolio and development of a single roadmap for NASA IT.

AGENCY IT SERVICES (AITS)

SAFEGUARDING NASA'S DATA AND IT ASSETS

The Agency is replacing ten standalone Center visitor management solutions with a single enterprise solution. This enterprise solution enables NASA to track visitors and the frequency of visits agency-wide; and, streamlines the process for visitor requests at Centers. NASA is also modernizing its Consolidated Active Directory. This modernization effort enhances cybersecurity and the Agency's ability to leverage new technologies; and, utilize the latest operating system updates. The Agency is also developing a web service that will enable application developers to seamlessly tie together data or functionality. This solution increases efficiencies by allowing information sharing across applications and NASA partners.

Plans are underway to complete CDM Phase 1 by deploying automated cybersecurity tools on its mission networks to gain a complete view of what devices are on its networks. NASA is also working towards deploying CDM Phase 2 tools to better manage users and their accounts (including privileged users with enhanced network access) and limit user-based vulnerabilities.

NASA is in the process of reinforcing its network and IT infrastructure cybersecurity with the deployment of tools designed to secure the external network perimeter and monitor for malicious attacks. The Agency is also enhancing cybersecurity capabilities of its SOC and IT Security Program (includes improvements to incident response, insider threat management, continuity of operations, enterprise cyber security architecture, cybersecurity risk management, and cybersecurity workforce development).

SERVICE DELIVERY

The Information Management (IM) Program is increasing development and use of registries to identify code, data, application programming interfaces (APIs), and Open Research Access Projects. This activity will improve NASA’s management of information assets; and, address the requirements of the Open Gov and Data Act legislation. Building on the email classifier algorithm developed in 2017, NASA is designing automated email-sorting techniques using natural language processing and machine-learning approaches. In 2018, NASA is applying the machine learning algorithm to the Technical Reports and indexing and search and build capabilities. For data-centric information collection processes, NASA will design a repository for optimized database-derived, user-friendly templates for use by forms designers across the Agency.

NASA will initiate Microsoft Office 365 implementation to leverage commercial cloud solutions for email, office productivity suites, collaboration, workforce mobility and cybersecurity. This implementation includes the EUS Program in order to improve NASA’s cybersecurity posture for end user devices and introduce desktop virtualization to the Agency. The NASA Enterprise Service Desk is focusing on improving customer service and satisfaction by implementing new technologies for customer-agent online chat; remote diagnostics and correction of end user issues; catalog enhancements to increase mobile access and analytics and data management platforms to identify service and performance improvement opportunities.

NASA will use information provided by the CASB tool implemented in FY 2017 to improve governance over NASA’s SaaS products. NASA will continue to use the initial commercial Infrastructure as a Service (IaaS) provider and will on-board many new cloud services for use in alignment with the Federal Risk and Authorization Management Program (FedRAMP). In FY 2018, the Agency will complete the remaining steps to onboard a second IaaS provider and will begin planning activities for onboarding a third major IaaS provider. In FY 2018, NASA anticipates closing three data centers.

AGENCY IT SERVICES (AITS)

The Agency will complete containerization of enterprise business applications while simultaneously implementing collaboration and continuous delivery; streamlining application updates and maintenance and reducing operational costs. A certificate lifecycle management capability will also be added to NASA's mobile device management service to provide secure encrypted email and Wi-Fi to iOS and Android devices.

In 2018, the Agency is engaging in several key initiatives. NASA is updating its current learning management and training solution to a cloud-based solution as the current system is at end-of-life. The service catalog for managed cloud services is currently undergoing testing and will be deployed during the fiscal year. The Agency will deploy a cloud-based electronic file and share capability designed to meet cybersecurity standards and policies. The Agency is prototyping server-less web site technology that will improve cybersecurity and reduce costs. The Agency will update the NASA Aircraft Management Information System (NAMIS) software. NAMIS is an integrated system that provides the basis for certification of airworthiness for NASA aircraft and holds aircraft configuration and compliance records, parts requirements, and maintenance records.

NASA’s Communications Program will complete the Agency-wide transition to the improved mission-wide area backbone and decommission legacy services as a cost reduction measure. NASA will also replace aging mission voice systems and migrate from obsolete time-division multiple technology to internet-protocol, and implement an alternate operating facility to improve continuity of operations capabilities.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

IT GOVERNANCE AND OVERSIGHT

In FY 2019, OCIO will utilize NASA’s IT governance to optimize spending, reduce duplication, and better secure data and IT assets. Through governance, OCIO plans to establish greater accountability, cost ownership, and economic rationale to manage daily IT decisions. To that effect, the Agency will collect IT estimates and spending for data analytics and budget management processes. The Enterprise Architecture program will proceed with the development of cross-cutting roadmaps with assistance from the NASA IT programs. The Program will continue to coordinate with NASA Center Enterprise Architects while conducting additional Center reviews.

SAFEGUARDING NASA'S DATA AND IT ASSETS

NASA will develop solutions for storage and protection of code signing private keys. To further increase efficiencies, the Centers Enterprise Physical Access Management Systems will be consolidated into a single enterprise solution. The Agency plans to make significant progress towards removing the use of username and passwords to access NASA applications and systems; and, replacing with more efficient private keys.

To ensure that NASA networks are safeguarded from unauthorized and potentially malicious connections and access, the OCIO plans to deploy its Enterprise Internal Border Network Access Control (EIB-NAC) project. The EIB-NAC cybersecurity tools will enable NASA to effectively manage user network access by placing users in network zones commensurate with cybersecurity policies.

AGENCY IT SERVICES (AITS)

The OCIO plans to standup a formal cybersecurity risk management program that will integrate cybersecurity risk management processes across the agency. This risk management program will also lead efforts to fully implement the NIST Cybersecurity Framework at NASA; and, conduct ongoing capabilities assessments to improve cybersecurity operations and inform risk-based decisions on strategic cybersecurity investments. IT Security will also begin to plan and develop a contract for all cyber security services with the implementation of the new Enterprise Security Services Office (ESSO). The Security Operations Center (SOC) will also be an element of this new enterprise cyber security contract.

SERVICE DELIVERY

The Agency plans to complete a comprehensive review and assessment of all space-based and ground-based science mission data; and incorporate the data into its information architecture framework. This comprehensive view of NASA’s science data will enhance OCIO's ability to classify the data and catalog the range of metadata standards and taxonomies used within the science missions. NASA plans to increase the number of scientific and technical documents in the repositories and apply automation techniques for classifying documents. These automation techniques will be compatible with the format required by the National Institutes of Health (NIH) for depositing in the NIH PubMed Central repository.

The EUS Program will expand use of the Agency’s enterprise contract for end user services beyond eighty (80) percent utilization and develop a strategy for managing all end user client systems. EUS will redesign the service catalog, enhance remote user capabilities, and increase efficiency of the Enterprise Service Desk.

The Agency expects an increase use of IaaS services as mission programs and projects realize the benefits of the IaaS cloud model. The Agency plans to make significant progress onboarding a third IaaS provider to provide NASA with a richer catalog of services and options to support NASA’s diverse missions, programs, and projects. OCIO also plans to complete additional migrations of premise-operated software to the cloud model and continues to perform data center optimization activities through consolidation, virtualization of underutilized systems and application rationalization efforts. OCIO will also eliminate inefficient equipment, migrate applications to the cloud, and implement infrastructure energy efficiencies.

In FY 2019, the Agency will deploy several key initiatives. NASA will explore new technologies and partner with other Federal Agencies and lower costs while bringing new services and capabilities to the Mission Directorates and support organizations. IT portfolio rationalization will continue to target websites and applications for reduction and consolidation and complete the migration of NASA IT collaboration services to cloud-based solutions. NASA will deploy a new end-to-end talent acquisition capability that will provide hiring managers with workflow transparency and provide applicants with status information throughout the hiring process. The Agency will deploy an easily accessible contract data repository to facilitate more effective strategic sourcing and acquisition activities. NASA’s managed cloud services ordering and provisioning automation will be completed in FY 2019. The OCIO plans to deploy an integrated data management capability to analyze facilities management decisions. Implementation of NAMIS will enhance mobility and the overall user experience, including functionality for a deployed aircraft when internet connectivity is unavailable.

NASA's Communications Program plans to fully transition Agency telecommunications services to the General Services Administration (GSA) Enterprise Infrastructure Solutions (EIS) contracts and terminate NASA’s GSA Network services. The EIS program will initiate replacement of obsolete mission voice systems and will complete the migration to VoIP for additional Centers. The program will unify IP-based

AGENCY IT SERVICES (AITS)

voice, video, and web conferencing services. Transition them to cloud-based technologies, complete design, implementation and activation of the Agency communications Alternate Operating Facility (AOF) and then complete the design and acquisition strategy for NASA's next generation mission voice capability.

IT INVESTMENTS

IT investments will enable NASA to improve cybersecurity, reduce costs and increase efficiencies by modernizing Agency systems, increasing automation, delivering affordable enterprise-wide IT service solutions, strengthening technical capabilities, and achieving cost avoidances and savings through strategic investments.

Several projects are critical to maintaining cybersecurity and continuous operations. These include: mission network cyber security modernization, which will reduce carrier costs and improve the network for mission data and voice services; elimination of corporate network obsolescence, which will allow the OCIO to make network refresh decisions at the enterprise level while reducing redundancies and inefficiencies; and expanding enterprise collaboration tools, which will establish a standardized collaborative tool suite, introduce new technology to support end-user service, and save costs through strategic sourcing initiatives.

Program Elements

IT GOVERNANCE AND OVERSIGHT

OCIO provides Agency-level capabilities, tracking and manages IT services across Centers and Missions. In compliance with OMB guidance, Executive Orders, laws, and regulations, the IT Management team collaborates with stakeholders across the Agency to formulate and manage budgetary data. IT Management utilizes budget data to inform leadership on NASA’s IT footprint, drive IT investment decisions, identify opportunities to reduce IT costs and better secure NASA’s IT assets.

OCIO's Enterprise Architecture serves as the authoritative source for information technology planning and execution and reflects the collective visions, goals, objectives, capabilities and services for the Agency. As the Enterprise Architecture matures, the EA program continues to initiate innovative partnering relationships with NASA missions, mission support offices, and Centers.

AGENCY IT SERVICES (AITS)

SAFEGUARDING NASA'S DATA AND IT ASSETS

The Information Management Program is currently in the design and development phase. This phase focuses on gaining an Agency-level understanding and assessment of the flow of information. The program includes existing initiatives, such as Scientific and Technical Information (STI) and Research Access for federally-funded peer-reviewed publications; and, efforts to ensure information integrity as it relates to requirements under Records, Paperwork Reduction Act (PRA), 508, Privacy Act and Forms.

Digital transformation strategies include research on push-technologies, creation of an agency information architecture and tiered metadata standards, as well as digital registries for data, code, data management plans, digital object identifiers, APIs and analytics algorithms.

NASA's EUS Program provides high-quality, reliable and cost-effective service desk, end user computing, collaboration and content management systems and services in support of all NASA Federal and contract employees. Specific service types supported by the EUS Program are laptops, desktops, mobile devices, print, enterprise email, SharePoint, instant messaging, tier 0/1 service desk, tier two desk-side support, software patching and distribution, and other end user support capabilities. NASA's Marshall Space Flight Center (MSFC) hosts end user device services and the NASA Shared Services Center (NSSC) hosts the NASA Enterprise Service Desk.

NASA uses cloud computing across all Agency business areas and leverages all three cloud service models. NASA plans to complete all listed data center closures and continue working on improving data center efficiency metrics.

The Applications Program (AP) has responsibility for applications and web sites. The AP monitors the NASA applications ecosystem and identifies opportunities to simplify, eliminate and optimize applications usage. Each area under the Applications Program supports the AP Program Executive in areas of IT authority, portfolio management, enterprise architecture, investment reviews, oversight of web, and project status, and risks.

The Communications Program (CP) is NASA’s enterprise service provider for fully managed network and communications services. CP provides the following end-to-end enterprise services for mission, research, and corporate users: voice (mission-critical, voice over IP and telephones); conferencing (voice, video and web); video distribution; wide area, local area and data center networks; and Center and customer-unique services (cable plant, emergency warning systems, public address systems, radios, and cable television services).

The Agency's FY 2019 budget for cybersecurity includes funding to develop, modernize and enhance agency cybersecurity capabilities. NASA has prioritized improvements in several areas: cybersecurity program management, enterprise cybersecurity service delivery, network defense, strong authentication, SOC enhancements and the phased implementation of CDM tools and technologies. Cybersecurity projects have been aligned to the NIST Cybersecurity Framework to better identify capability gaps and develop plans to address the gaps. Within these priorities, NASA is pursuing key projects that enable the OCIO to develop and efficiently deliver proactive cybersecurity capabilities consistent with Federal targets and standards.

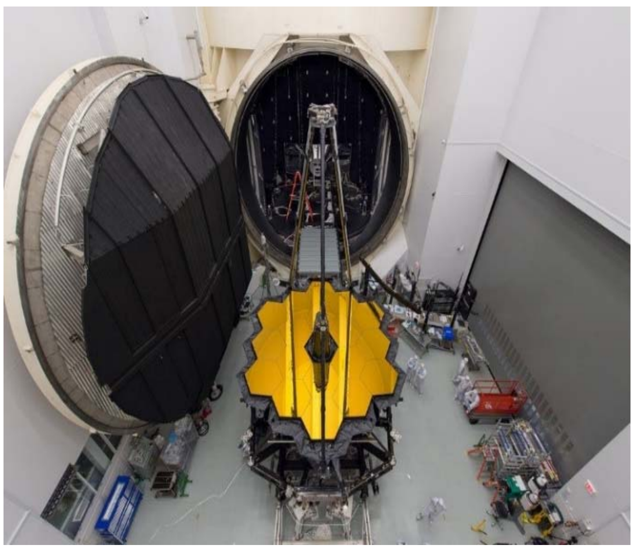
STRATEGIC CAPABILITIES ASSET PROGRAM

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**26.8**	**--**	**26.7**	**26.7**	**26.7**	**26.7**	**26.7**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



Preparations for testing of the Webb Optical Telescope Element/Integrated Science Instrument Module in Chamber A, located at NASA's Johnson Space Center, Houston, Texas.

The Strategic Capabilities Asset Program (SCA) ensures that select critical test facilities are operationally ready to meet mission and program requirements by sustaining a skilled workforce and periodically performing essential preventative maintenance. The Program supports essential core capabilities such as: thermal vacuum chambers, simulators, and arc jets.

SCA strategically and centrally manages Agency assets, reviews assets and capabilities annually among Centers to ensure the validity of facility requirements, identifies reinvestment and recapitalization requirements within and among asset classes, recommends disposition of capabilities no longer needed, and implements changes as required.

SCA insures maximum benefit across the government by broadening alliances outside the Agency for capabilities (e.g., thermal vacuum chambers). Facilitating this endeavor is the Space Environment Test Alliance Group, a collaborative working group consisting of NASA, the Department of Defense (DoD), and other partner entities. The members gain awareness of capabilities across agencies, academia, and industry; share best practices; provide technical support; and refer test programs to facilities best suited to meet test requirements.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None

STRATEGIC CAPABILITIES ASSET PROGRAM

ACHIEVEMENTS IN FY 2017

In FY 2017, SCA reviewed and identified high-risk thermal vacuum capability areas at Goddard Space Flight Center (GSFC) to assess the condition and health of its assets.

SCA managed capabilities supported NASA's mission by enabling the following:

- SCA’s Space Power Facility (SPF) at the GRC completed the Orion Service Module Structural Test Article testing series; SPF began the preparation for the Orion EM-1 Testing series;
- SCA’s thermal vacuum test facility Chamber A at JSC completed the, the thermal pathfinder testing, and conducted vacuum and cold soak testing for the Optical Telescope Element/Integrated Science Instrument Module (OTIS) hardware for Webb;
- SCA’s 25’ Space Simulator at JPL began to support Mars Helicopter development testing; and
- SCA's Vertical Motion Simulator (VMS) at the ARC began the Motion Cue 4 testing for the Federal Aviation Administration (FAA).

WORK IN PROGRESS IN FY 2018

In FY 2018, SCA will assess the condition and health of the space environments testing capability at GRC; and will review and identify high-risk areas such as loss of controls due to equipment failure.

SCA will remove the GSFC Six-Degrees of Freedom vibration shaker and the LaRC Visual Motion Simulator from service due to lack of future demand and requirements.

SCA managed capabilities are supporting NASA's mission by enabling the following:

- The Space Power Facility (SPF) at GRC will support the Orion EM-1 testing series and the SpaceX Falcon 9 Fairing Acoustic testing.
- The thermal vacuum test facility Chamber A at JSC will continue to support Webb Telescope and complete the testing of the Optical Telescope Element and the Integrated Science Instrument Module. Chamber A will transition to stand-by mode after the completion of testing series for the Webb Telescope.
- The Vertical Motion Simulator (VMS) will continue to support the Federal Aviation Administration (FAA) in testing to study differences in pilot performance in several aircraft tasks under different simulator motion configurations.
- The Cockpit Motion Facility (CMF) and the Boeing Company will work together under a new Space Act Agreement to improve flight training and aviation safety using NASA’s synthetic vision technologies and Boeing’s 787 simulators.
- The Arc Jets at ARC will continue to support Thermal Protection System development for Orion.

STRATEGIC CAPABILITIES ASSET PROGRAM

KEY ACHIEVEMENTS PLANNED FOR FY 2019

In FY 2019, SCA will assess the condition and health of the simulation testing capability at Ames Research Center (ARC) and Langley Research Center (LaRC) and will review and identify high-risk areas such as equipment failure due to age or maintenance.

SCA will continue to sustain strategic technical capabilities required by NASA to achieve mission success.

SCA will continue to support the development, testing, verification, and validation for NASA, DoD, National Oceanic and Atmospheric Administration (NOAA), Federal Aviation Administration (FAA), and commercial companies in the following areas:

- Simulators: air traffic management technology demonstration, Unmanned Aerial System airworthiness standards and guidelines, motion cueing, loss of control and recovery, enhanced stall modeling, and other ongoing development and testing;
- Thermal vacuum and acoustic chambers: Orion, Webb, Mars2020, Eurpoa, NiSAR, SWOT, NASA-Indian Space Research Organization Synthetic Aperture Radar, Commercial Crew and Crew Cargo launch program testing, and other space environmental testing; and
- Arc Jets: thermal protection materials, system development, and qualification testing.

Planned testing in SCA managed assets include:

- The Space Power Facility (SPF) at GRC continues to support Orion in thermal vacuum and acoustics and vibrations testing.
- The NASA Arc Jet complex at ARC continues to support Orion heat shield development testing.

Program Elements

SCA maintains a highly skilled workforce that performs maintenance required to utilize and preserve essential national assets uniquely capable of meeting program requirements.

SIMULATORS

Simulators are of critical importance to the success of NASA’s Aeronautics Research in the areas of fundamental aeronautics and aviation safety. These capabilities provide scientists and engineers with tools to explore, define, and resolve issues in both vehicle design and missions operations.

This capability includes an array of simulator assets used in the research and development (R&D) of flight and crewed operations phase:

- The Vertical Motion Simulator and its associated laboratories and equipment located at ARC; and
- The Cockpit Motion Facility and its supporting suite of simulators (the Differential Maneuvering Simulator and the Visual Motion Simulator) and central support facilities for aeronautics and spaceflight vehicle research located at LaRC.

STRATEGIC CAPABILITIES ASSET PROGRAM

THERMAL VACUUM, VACUUM AND ACOUSTIC CHAMBERS

This capability includes assets located at the following Center: AFRC, ARC, GRC, GSFC, JPL, JSC, KSC, LaRC, MSFC, White Sands Test Facility, Plum Brook Station, and Wallops Flight Facility. These assets have a minimum size threshold and, in some cases, can accommodate a complete spacecraft. Acoustic Chambers can generate similar noise levels experienced during launch. Thermal Vacuum and Vacuum Chambers can simulate ultra-low pressures and low temperatures experienced in deep space.

These chambers are used to perform significant risk mitigation for most NASA payloads launched into space, as well as many payloads in other government agencies, such as the National Oceanic and Atmospheric Administration (NOAA) and DoD. Testing performed in these chambers ensures that the equipment, sub-systems, and assembled spacecraft will meet strict requirements of harsh launch and space environments. Recent successful tests in the thermal vacuum and acoustic chambers include NASA's Magnetospheric Multiscale Mission (MMS), European Space Agency's Ariane launch vehicles, and SpaceX launch vehicle payload fairing separations.

ARC JET

The Arc Jet capability is located at ARC and includes assets that provide simulated high-temperature, high-velocity environments and support the design, development, test, and evaluation activities of thermal protection materials, vehicle structures, aerothermodynamics, and hypersonic aerodynamics. A gas (typically air) is heated using a continuous electrical arc and accelerated to supersonic/hypersonic speeds. This high-temperature gas passes over a test sample and produces an approximation of the surface temperature and pressure environments experienced by a vehicle on atmospheric entry.

HEADQUARTERS BUDGET BY OFFICE

AGENCY MANAGEMENT BUDGET BY HEADQUARTERS OFFICE

	Actual	CR	Request	Notional			
($ in millions in full cost)	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**	**FY 2023**
Aeronautics Research	6.8	6.6	6.7	6.7	6.7	6.7	6.7
Human Exploration and Operations	29.5	29.1	29.1	29.1	29.1	29.1	29.1
Science	30.9	30.6	29.6	29.6	29.6	29.6	29.6
Space Technology	5.4	5.4	5.2	5.2	5.2	5.2	5.2
Mission Directorates	**72.6**	**71.7**	**70.7**	**70.7**	**70.7**	**70.7**	**70.7**
Office of the Administrator	5.8	5.8	5.9	5.9	5.9	5.9	5.9
Office of Strategy and Plans	2.5	2.2	2.1	2.1	2.1	2.1	2.1
Chief Engineer	4.3	4.0	4.1	4.1	4.1	4.1	4.1
Chief Financial Office	34.5	34.5	33.9	33.7	33.1	32.5	31.9
Chief Health and Medical Office	1.9	1.8	1.8	1.8	1.8	1.8	1.8
Chief Information Office	9.3	9.1	9.1	9.1	9.1	9.1	9.1
Chief Scientist	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Chief Technologist	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Communications	13.7	14.1	14.0	14.0	14.0	14.0	14.0
Diversity and Equal Opportunity	3.9	3.6	3.6	3.6	3.6	3.6	3.6
Education	2.7	2.6	2.6	2.6	2.6	2.6	2.6
General Counsel	9.7	9.5	9.5	9.5	9.5	9.5	9.5
International and Interagency Relations	13.0	12.3	12.2	12.2	12.2	12.2	12.2
Legislative and Intergovernmental Affairs	3.8	3.6	3.5	3.3	3.3	3.3	3.3
Safety and Mission Assurance	7.6	7.3	7.2	7.2	7.2	7.2	7.2
Small Business Programs	1.9	1.8	1.9	1.9	1.9	1.9	1.9
Staff Offices	**117.0**	**114.6**	**113.8**	**113.4**	**112.8**	**112.2**	**111.6**
NASA Management Office at JPL	9.1	8.6	9.7	9.7	9.7	9.7	9.7
Human Capital Management	8.4	8.9	8.9	8.6	8.6	8.6	8.6
Headquarters Operations	94.3	99.7	101.7	101.7	101.7	101.7	101.7

HEADQUARTERS BUDGET BY OFFICE

	Actual	CR	Request	Notional			
($ in millions in full cost)	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**	**FY 2023**
Strategic Infrastructure	16.2	15.6	15.6	15.6	15.6	15.6	15.6
Procurement	11.9	11.0	11.2	11.2	11.2	11.2	11.2
Mission Support Directorate Front Office	4.3	4.0	4.1	4.1	4.1	4.1	4.1
NASA Shared Services Center	4.8	4.8	4.9	4.9	4.9	4.9	4.9
Protective Services	20.6	19.6	18.9	18.9	18.9	18.9	18.9
Mission Support	**169.6**	**172.3**	**175.0**	**174.7**	**174.7**	**174.7**	**174.7**
Total, Agency Management	**359.2**	**358.6**	**359.5**	**358.8**	**358.2**	**357.6**	**357.0**

HEADQUARTERS WORKFORCE BY OFFICE

HEADQUARTERS WORKFORCE BY OFFICE

	Actual				Estimated				Request			
	FY 2017				**FY 2018**				**FY 2019**			
	FTE	**SES**	**NC***	**WYE**	**FTE**	**SES**	**NC***	**WYE**	**FTE**	**SES**	**NC***	**WYE**
Aeronautics Research	33	8	0	10	33	8	0	11	33	8	0	11
Human Exploration and Operations	139	18	0	56	141	18	0	57	138	18	0	58
Science	152	21	0	64	155	22	0	64	152	22	0	64
Space Technology	32	3	0	5	32	3	0	13	31	3	0	12
Mission Directorates	**356**	**50**	**0**	**135**	**361**	**51**	**0**	**145**	**354**	**51**	**0**	**145**
Office of the Administrator	23	6	2	2	23	6	4	2	23	6	4	2
Office of Strategy and Plans	3	0	1	2	3	0	1	2	3	0	1	2
Chief Engineer	19	4	0	0	19	4	0	0	19	4	0	0
Chief Financial Office	108	10	0	42	109	10	0	42	106	10	0	42
Chief Health and Medical Office	9	3	0	2	9	3	0	2	9	3	0	3
Chief Information Office	44	5	0	49	44	5	0	77	44	5	0	77
Chief Scientist	6	1	0	0	6	2	0	0	6	2	0	0
Chief Technologist	4	1	0	0	4	1	0	0	4	1	0	0
Communications	45	1	2	27	45	2	2	27	45	2	2	27
Diversity and Equal Opportunity	12	1	0	1	12	2	0	1	12	2	0	1
Education	13	2	0	6	13	2	0	0	12	2	0	0
General Counsel	40	6	0	0	40	6	0	0	39	6	0	0
International and Interagency Relations	48	7	0	7	48	7	0	7	47	7	0	7
Legislative and Intergovernmental Affairs	22	1	2	0	22	1	2	0	21	1	2	0
Safety and Mission Assurance	35	6	0	7	35	6	0	7	34	6	0	7
Small Business Programs	5	1	0	4	5	1	0	4	5	1	0	4
Staff Offices	**437**	**55**	**7**	**149**	**437**	**58**	**9**	**171**	**429**	**58**	**9**	**172**
NASA Management Office at JPL	24	2	0	0	24	2	0	0	29	2	0	0
Human Capital Management	34	5	0	15	34	5	0	15	34	5	0	15
Headquarters Operations	97	4	0	340	98	4	0	340	95	4	0	333
Strategic Infrastructure	53	5	0	2	53	5	0	2	52	5	0	2
Procurement	33	4	0	0	34	4	0	0	34	4	0	0
Mission Support Directorate Front Office	16	4	0	1	16	4	0	1	16	4	0	1
Protective Services	48	3	0	6	48	3	0	6	47	3	0	6
Mission Support	**306**	**27**	**0**	**364**	**307**	**27**	**0**	**364**	**307**	**27**	**0**	**357**
Total Agency Management	**1,099**	**132**	**7**	**648**	**1,105**	**136**	**9**	**680**	**1,090**	**136**	**9**	**674**

**NC is Non-Career*

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Construction of Facilities	305.4	--	**305.3**	210.9	210.9	210.9	210.9
Environmental Compliance and Restoration	70.2	--	**82.9**	82.9	82.9	82.9	82.9
Total Budget	**375.6**	**358.3**	**388.2**	**293.8**	**293.8**	**293.8**	**293.8**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

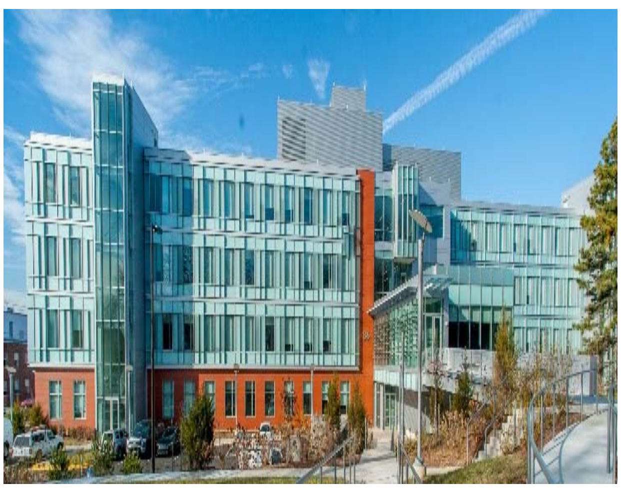
CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Construction of Facilities	305.4	--	**305.3**	210.9	210.9	210.9	210.9
Environmental Compliance and Restoration	70.2	--	**82.9**	82.9	82.9	82.9	82.9
Total Budget	**375.6**	**358.3**	**388.2**	**293.8**	**293.8**	**293.8**	**293.8**
Change from FY 2018			**29.9**				
Percentage change from FY 2018			**8.3%**				

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.



The Flight Projects Building at the Goddard Space Flight Center (GSFC) earned a Leadership in Energy and Environmental Design (LEED) Gold certification in 2017. NASA's inventory of high performance facilities now exceeds 3.3 million square feet.

NASA designs and implements its construction of facilities projects, facility demolition projects, and environmental compliance and restoration activities through its Construction and Environmental Compliance and Restoration (CECR) account.

Construction of Facilities (CoF) makes capital repairs and improvements to NASA's infrastructure and provides NASA programs and projects with the research, development, test and evaluation (RDT&E) facilities required to accomplish their missions. About 82 percent of NASA's infrastructure and facilities are beyond their constructed design life, requiring strong risk management programs to mitigate risk to current and future missions. Apollo-era legacy infrastructure is especially inefficient and costly to maintain and operate. To address these challenges, NASA's programs focuses on reducing and modernizing NASA's infrastructure into fewer, more efficient sustainable facilities.

Environmental Compliance and Restoration (ECR) projects clean up pollutants released into the environment at NASA installations, NASA-owned industrial plants supporting NASA activities, current or former sites where NASA operations have contributed to environmental problems, and other sites where the Agency is legally obligated to address hazardous pollutants. NASA prioritizes these cleanups to protect human health and the environment, and preserve natural resources for future missions.

Together, these construction and remediation activities help ensure that NASA's assets are ready, available, and appropriately sized to conduct NASA's missions, and that NASA facilities are compliant with current environmental regulations.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

NASA completed several significant infrastructure projects, including the Logistics and Maintenance Facility, No. 351, Phase 2 (GRC), which provides the shop and office space to relocate center logistic and maintenance functions. Also completed were the GSFC Fire Station, and the Human Health and Performance Facility (JSC), which reduced the agency's footprint and significant maintenance cost by consolidating seven facilities into one facility. NASA completed construction on the ATCC HVAC Refurbishment Project (SSC). This project included replacing a chiller and an air handler, and upgrading the controls.

NASA initiated projects to repair and revitalize its infrastructure. A key recapitalization project is the Biosciences Collaborative Facility (ARC) to consolidate existing laboratories into a smaller efficient and modern research facility. Other Discrete Projects include: Repair Emergency Power System for Mission Control Center, Emergency Power, B48 (JSC), Compressor Station Upgrades, Phase 2 (LaRC), Revitalize Building Electrical Systems (Building 4708) (MSFC), Steam Distribution Replacement, Phase 1 (MSFC), and the Rehabilitate Site-wide HPG HE, GN and Air Distribution, Phase 2 (SSC).

To reduce the Agency's footprint, NASA disposed of approximately 167,753 square feet of buildings for a net reduction of 123,490 SF.

NASA continued the Energy Savings Investments portion of Institutional CoF by continuing expansion of the Central Campus solar photovoltaic system at KSC; implementing HVAC and lighting efficiency projects at GRC, GSFC, JSC, and KSC; and replacing window walls on mall area buildings at JSC. The program also initiated projects to install a solar photovoltaic system on the parking structure at JPL, and install a high-efficiency replacement boiler at MSFC.

Programmatic CoF activities made significant progress on transitioning facilities to support the Space Launch System (SLS) and Orion Programs for Exploration Missions. At KSC, the Vehicle Assembly Building (VAB) and the Launch Complex 39B (LC-39B) are in final stages of construction. In the VAB, Ground Systems Development and Operations (GSDO) installed 20 platform levels (A-K) in high bay 3 including mechanical, electrical and plumbing support systems, egress ramp access, new elevator landing platforms and facility utility subsystems to support SLS launch vehicle and Orion spacecraft processing. At LC-39B, modifications to the environmental control systems to support SLS and Orion, as well as the re-bricking the flame trench is complete. Fabrication and assembly of all new steel flame deflector components are in final stages of completion. Other significant work at LC-39B included construction of the liquid hydrogen liquid-gas separator tank and reinforcement of the catacomb roof structure that was necessary to accommodate the combined weight of the launch vehicle and mobile launcher.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

NASA completed major construction at the Stennis Space Center on the B-2 Test Stand in preparation for the SLS Green Run Testing. The construction on the B-2 raised the height of the core superstructure up to the 345-foot level, preparing the stand for testing the SLS Core Stage. Work completed included installation of the cryogenic piping for the Liquid Oxygen, Liquid Hydrogen, and all of the Gaseous Helium, Nitrogen, and High-Pressure Air Piping. In addition, the tarmac in front of the test stand was improved and strengthen to allow the larger and heavier SLS Core Stage to roll off the barge prior to being lifted in to stand.

For the Deep Space Network Aperture Enhancement Project, Phase II construction continued in Madrid, Spain.

NASA procured a second modular supercomputing unit for the proof-of-concept prototype for the Modular Supercomputing Facility at ARC. The prototype demonstrates the feasibility of new energy-efficient and water-conserving modular computing technology, enabling the increase of NASA's supercomputing capability with minimal impact on limited energy and water resources.

Within the ECR program:

- Santa Susana Field Laboratory (SSFL) continued demolition of buildings not associated with test stands and development of work plans for soil cleanup, continued soil, and groundwater cleanup treatability studies, groundwater field investigations, operations of groundwater treatment system and long-term monitoring of groundwater. Cultural resource actions were continued per the Programmatic Agreement with the State Historic Preservation Office, Native Americans, and consulting parties;
- MSFC completed soil cleanup at petroleum sites and developed designs for the Industrial Sewer operable unit remedial action and monitoring/ characterization of groundwater;
- Glenn Research Center (GRC) continued decontamination and decommission of the cyclotron building under NRC license termination;
- Michoud Assembly Facility (MAF) began thermal treatment pilot scale remediation of groundwater at the former rinse water impoundments;
- White Sands Test Facility (WSTF) continued to operate the plume front and mid-plume front treatment systems to capture and treat contaminated groundwater. They also continued source area investigations and closure activities of the sewage lagoon;
- KSC installed several new groundwater treatment systems, completed extensive contaminated soil removal at various sites, continued sampling of over 400 monitoring wells, and continued operations of existing groundwater cleanup systems;
- At the JPL, the program continued to operate and maintain systems to clean up contaminated groundwater emanating from the laboratory, and operations and system upgrades to the Lincoln Avenue and Monk Hill drinking water treatment systems.

WORK IN PROGRESS IN FY 2018

NASA planned Institutional CoF projects that will protect the Agency's critical assets, improve mission assurance, reduce mission risk, and maintain mission essential capabilities. These include utility system repairs and replacement of obsolete buildings. Work continues on the following significant projects:

- Construction of the Biosciences Collaborative Facility that will consolidate and modernize existing technical facilities at ARC. The new complex will support biological research and development initiatives unique to the Agency to support Fundamental Space Biology, Astrobiology/Exobiology, and Synthetic Biology;
- Repair Emergency Power System for Mission Control Center- Emergency Power B48, NASA (JSC), Compressor Station Upgrades NASA (LaRC), Revitalize Building Electrical Systems (4708) (MSFC), and Steam Distribution Replacement NASA(MSFC);
- NASA (KSC) Central Campus Phase 1 – construction is ongoing to complete the modernization and consolidation at Kennedy Space Center. These upgrades will incorporate sustainable and energy efficient design.

In the Energy Savings Investments, NASA initiated a project to replace the window walls of the mall area buildings at NASA (JSC). This will reduce energy intensity by decreasing solar heat gain and outdoor air infiltration.

Exploration construction activities continue to focus on meeting the first Exploration Mission (EM-1). NASA will initiate the first of two construction projects at KSC and GSDO to upgrade and modify infrastructure in support of SLS Block 1B EM-2 launch requirements. At LC-39B, a fabricated 1.25M gallon (est.) LH2 Dewar sphere, along with a vaporizer, flare stack and associated piping/valve system will be installed. Within the VAB, construction of a new Environmental Control System (ECS) along with design commencement of HB3 and HB4 platforms to support EM-2 EUS increased load demands.

NASA will continue with their efforts at MAF, to work on modifications to Building 103 and Building 110 to support SLS Core Stage manufacturing. Construction planned to be completed in FY 18 includes: Building 103 Final Integration (Fall Protection), Fan House and Substation Structural Repairs in Building 103-Ph 1, rehabilitating the Chilled Water / Steam Distribution Piping, replacing and rehabilitating Substations 20A, 43, 63 and 64, replacing the Purlins in Building 103 Phase 2, and repairing the Fan House and Substation Structural Support Repairs Phase 1. Work will initiate on replacing Substation No. 1, repairing Fan House and Substation Structural Support Repairs in Building 103 Phase 2, replacing the Purlins in Building 103 Phase 2 and repairing the roof of Building 102.

The two structural test stands at MSFC will be completely activated and operational. Minor open work after acceptance will be completed, including the installation of egress lighting on the roof of TS4693 and additional engineering documentation from the Architecture & Engineering (A&E) firm.

SCaN will continue the second phase of the DAEP, a multi-year funded discrete project to construct the two new 34-meter BWG DSS Antennas, DSS-56 and DSS-53, at the Madrid Deep Space Communications Complex. The DSN will also complete the BWG Antenna Chiller Replacement project. This project will provide reserve chiller systems and three water-cooling, purification, and storage systems for supporting the BWG transmitters throughout the Network.

Facilities at MAF sustained significant damage from an EF-3 tornado on February 2, 2017. Damage included major impacts to multiple buildings within the facility and SLS Ground Support Equipment. NASA received $109 million in supplemental funding in FY 2017 to repair major and minor damages to fifteen (15) MAF facilities, demolish three (3) totally damage buildings and emergency response and cleanup.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

NASA received $75 million in supplemental funding in FY 2017 to repair the facilities damaged at KSC by Hurricane Matthew. Emergency repair and recovery to numerous facilities is underway, including repair of the Operations Support Building II, the Booster Fabrication Facility, JJ Railroad Bridge, and Electrical Shop. Design for the full repair to the Utility Annex Building has been completed, and construction began at the end of FY 2017.

SSFL will continue demolition of structures in areas not associated with the Test Stands. Submit cleanup plans for soil and groundwater. Continue operations of groundwater treatment system and long-term monitoring of groundwater. Cultural resource actions will continue per the Programmatic Agreement with the State Historic Preservation Office, Native Americans, and consulting parties.

GRC will continue decontamination and decommission of the cyclotron building under NRC license termination.

KSC will continued investigation and cleanup of groundwater and soil contamination. Activities planned include the installation of new groundwater treatment systems, removal of contaminated soils, investigation of additional sites for potential contamination, continued sampling of over 400 monitoring wells, and continued operations of existing groundwater cleanup systems.

ARC will begin landfill remediation and final closure per Federal Facilities Agreement.

MSFC will begin cleanup of the Industrial Sewer operable unit and monitoring/ characterization of groundwater.

WSTF will continue to operate the plume front and mid-plume front treatment systems to capture and treat contaminated groundwater and continue source area investigations and closure activities of the sewage lagoon.

Continue operations of treatment systems and monitoring at AFRC, GSFC, LaRC, MAF, SSC, and WFF.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

NASA planned construction and environmental activities include:

- Major repair and replacement projects that address deficiencies noted by the National Academies and support core NASA research efforts;
- Commence construction of the following critical recapitalization projects: Instrument Development Facility (GSFC) and the Research Support Building (GRC);
- Repairs and upgrades at the Centers to mitigate near-term risk to missions by revitalizing electrical, mechanical, life safety, sanitary sewer and water systems;
- Investments to reduce energy cost and consumption to increase progress toward Federal energy requirements;
- Demolition to eliminate obsolete facilities and reduce footprint;
- New construction at in the VAB and at the LC-39B to support the new Exploration Upper Stage (EUS) required for EM-2, a manned flight beyond low earth orbit (KSC);

- Continued cleanup of ground water contamination and investigation of soil contamination at WSTF, to include completion of closure activities, implementation of source area facility investigations, long-term monitoring of groundwater, and continued operation of the plume front and mid-plume ground water treatment systems;
- Continued investigation and cleanup of groundwater and soil contamination at KSC under State of Florida requirements. Key activities planned include the installation of new groundwater treatment systems, removal of contaminated soils, investigation of additional sites for potential contamination, continued sampling of over 400 monitoring wells, and continued operations of existing groundwater cleanup systems;
- Operate and maintain systems to clean up contaminated groundwater emanating from JPL and continued operations of the Lincoln Avenue and Monk Hill drinking water treatment systems; and
- Demolition, cleanup of contaminated soils, continued operations of groundwater treatment systems, and continued long term monitoring of groundwater at SSFL in accordance with the State of California. Cultural resource actions will continue per the Programmatic Agreement with the State Historic Preservation Office, Native Americans, and consulting parties.

CONSTRUCTION OF FACILITIES

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Institutional CoF	253.2	--	**250.9**	210.9	210.9	210.9	210.9
Exploration CoF	8.8	--	**25.9**	0.0	0.0	0.0	0.0
Space Operations CoF	36.7	--	**18.9**	0.0	0.0	0.0	0.0
Science CoF	2.7	--	**9.6**	0.0	0.0	0.0	0.0
Aeronautics CoF	4.0	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**305.4**	**--**	**305.3**	**210.9**	**210.9**	**210.9**	**210.9**

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The MSFC Steam Distribution System is the second of a two phase project to convert buildings to a more efficient natural gas fired boiler system that reduces operating and maintenance costs.

NASA’s CoF program includes programmatic and non-programmatic construction projects that reduce facility-related risk to mission success and increase sustainability.

The Institutional CoF program provides for the design and construction of facilities projects that enable NASA’s infrastructure to meet mission needs. Utility system repairs and replacements improve the reliability of NASA’s systems and reduce operational consumption of energy. Refurbishment or repair-by-replacement projects replace inefficient, deteriorated buildings with efficient high-performance facilities. Demolition projects eliminate facilities that are no longer needed. Together these activities reduce operating costs, reduce the Agency footprint, and develop an energy efficient infrastructure to enable NASA’s missions.

Programmatic CoF provides specialized capabilities in testing and development that directly support NASA’s missions. These projects enable NASA to provide critical technical capabilities to manufacture, test, process, or operate hardware for NASA programs.

CONSTRUCTION OF FACILITIES

Discrete projects refer to those with initial cost estimates of $10 million or greater. Minor projects are those with initial cost estimates between $1 and $10 million; and are subject to change according to priorities. Centers accomplish routine day-to-day facility maintenance and repair activities with estimates of $1 million or less within program and Center Management and Operations budgets.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None

INSTITUTIONAL COF

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	253.2	--	250.9	210.9	210.9	210.9	210.9

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Rendering of the Aerospace Communications Facility at GRC. This building provides state of the art space for development of communications and navigation infrastructure, and service for human Lunar and Mars missions.

NASA's Institutional CoF program includes projects to reduce risk, increase efficiency, and reduce operational costs.

CoF projects repair and/or improve NASA's existing facilities and reduce facility-related risks to mission success, property, and personnel. NASA prioritizes these projects using a risk-informed process. Projects are to increase efficiency in support of NASA's core capabilities within a smaller, more efficient footprint. These include replacement of old, obsolete, costly facilities with new, high-performance facilities that consolidate core functions, reduce operating costs and improve flexibility over the life of the facilities. These replacement facilities are flexible so they can address programmatic requirements, both known and still evolving over the next 40 years.

NASA's demolition program eliminates obsolete, unneeded infrastructure to improve efficiency and eliminate safety and environmental risks.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

NASA constructs facilities using cost effective life-cycle analytic design methods to meet current Federal requirements. NASA executed numerous CoF projects, including construction of two new sustainable-rated facilities that provide 40,000 square feet of area to replace obsolete and inefficient facilities at JPL and WFF.

INSTITUTIONAL COF

During FY 2017, NASA:

Disposed of approximately 167,753 square feet of buildings for a net reduction of 123,490 SF. Demolition of 33 facilities accounted for approximately 142,147 square feet of the total 167,753 SF of buildings disposed. Demolition of inactive and obsolete facilities allow the Agency to avoid operating cost of maintaining old, and abandoned facilities in a safe and secure condition. Furthermore, demolition is the most cost-effective way to reduce the Agency's deferred maintenance. Finally, Demolition promotes environmental responsibility and community planning through the recycling of old construction materials and creating green space for future development. There are many benefits from these efforts such as supporting the Agency's mission to reduce the footprint and staying consistent with the facility master planning process.

NASA began construction of the following critical projects:

- Revitalize Industrial/Potable Water Distribution System (AFRC)
- Revitalize Mission Control Electrical Systems (AFRC)
- Reduce Seismic Risk to Buildings N226 N240 N244 & N245 (ARC)
- Replace Arc Jet Diffusers (ARC)
- Replace UPWT Three Stage Compressor Rotor Blade (ARC)
- GRC Repair Steam Distribution, Phase 3 (GRC)
- Continue LN2 Storage and Distribution Upgrade (JPL)
- Energy Management Control System, Phase 1 (JPL)
- Repair Central Heating and Cooling Plant Compressed Air System (JSC)
- Revitalize Water and Waste Water Systems, Phase 5 of 6 (KSC)
- Repaired Chilled Water Systems, Various Locations (KSC)
- Bldg. 831 Modification and Storage Consolidation, VAFB (KSC)
- Parking Repair and Lighting, Bldg. 836/839/840, VAFB (KSC)
- Upgrade VAB Utility Annex (KSC)
- Replace Operations Support Buildings 1&2 Roofs (KSC)
- Refurbish High Pressure Air (HPA) Dryer System (SSC)
- Rehabilitate/Repair Site-wide Natural Gas System (SSC)
- Site-side Hazard/Fire Detection System (SSC)

NASA completed construction of the following essential projects:

- Restore Electrical Reliability for Multiple Facilities (ARC)
- Replace UPWT Auxiliary 1000 KVA Transformers (ARC)
- Repair Aircraft Ramp (AFRC)
- Logistics and Maintenance Facility, No. 351, Phase 2 (GRC). This project provides the shop and office space to relocate logistic and maintenance functions that resided in Building 21.
- Repair Electrical Distribution, Phase 1 (GRC)
- Replace Island Fire Station (WFF)
- Data Center Restoration, B230 Data Center, Phase 2 (JPL)
- Safety Repairs and Upgrade, Site Electrical Substation, Building 221 (JSC)
- Replace Central Heating and Cooling Plant boiler, Building 24 (JSC)
- Human Health and Performance Facility, Building 2 (JSC)

INSTITUTIONAL COF

- Upgraded Water Wells and Distribution Systems (WSTF)
- Repair Water System Infrastructure, Large Altitude Simulation System (WSTF)
- Revitalize Water and Waste Water Systems, Various Locations, Phase 4 (KSC)
- Upgrade Systems, Industrial Area Chiller Plant (KSC)
- Deconstruct Facilities and Structures, Various Facilities (KSC)
- Modify VAB For SLS Platforms (KSC)
- Modifications for Hazardous Processing, Industrial Area, for Orion (KSC)
- Reinforce Catacomb Roof for SLS Block 1B Vehicle, LC 39B (KSC)
- Upgrade KSC Barge Terminal for SLS (KSC)
- Install Elevator, VAB Tower F (KSC)
- Pad B HVAC and Controls Refurbishment (KSC)
- Refurbish and Upgrade Pad B Water System Phase II (KSC)
- Construct Replacement NASA Causeway Duct Bank (KSC)
- Space Station Processing Facility Roof Replacement (KSC)
- Revitalize Building Mechanical Systems (Building 4755) (MSFC)
- Revitalize Chilled Water Station Electrical (Building 4473) (MSFC)
- Revitalize Building Electrical Systems (Building 4711) (MSFC)
- ATCC HVAC Refurbishment (SSC)
- NASA Continued the Energy Savings Investments portion of Institutional CoF by continuing expansion of the Central Campus solar photovoltaic system at KSC; implementing HVAC and lighting efficiency projects at GRC, GSFC, JSC, and KSC; and replacing window walls on mall area buildings at JSC. The program also initiated projects to install a solar photovoltaic system on the parking structure at JPL, and install a high-efficiency replacement boiler at MSFC.

WORK IN PROGRESS IN FY 2018

Significant work in progress includes:

- Award for construction for Repair Exterior of Engine Research Building West Wing, Building 23 (GRC),
- I&T Complex Electrical/Mechanical Repairs (GSFC)
- Safety Upgrades to the Public Water System, WSTF Phase 1 of 2 (JSC)
- Repair Sanitary Sewer System (JSC)
- Revitalize Water & Waste Water Systems, Various Locations, Phase 6 of 6 (KSC)
- Restore Coastal Shoreline, Phase 1 (KSC)
- Implement Mechanical Upgrades, Various Buildings (Energy Savings Investment) (KSC)
- Upgrade LH2 System, LC398 (KSC)
- B1293 Electrical Upgrades (LaRC)
- Electrical Distribution System Upgrades, West Taylor Street (LaRC)
- Revitalize Pressure & Propellant Distribution Systems, Site Wide, Phase 1 of 3 (MSFC)
- Electrical Repairs to SSC Canal and Navigation Lock Water Replenishment System (SSC)

INSTITUTIONAL COF

KEY ACHIEVEMENTS PLANNED FOR FY 2019

NASA is planning to complete several significant infrastructure projects under construction, including:

- Restore Power Supply Reliability of Arc Jet Facility (ARC)
- Replace Arc Jet Diffusers (ARC)
- Reduce Seismic Risk to Bldgs. N226, N240, N244 & N245 (ARC)
- Repair Central Compressed Air Equipment, Phase 2 (GRC)
- Repair Domestic Water Main, Phase 2 (GRC)
- 9x15 Low Speed Wind Tunnel Phase 1&2 (GRC)
- Airfield Repairs (GSFC)
- Upgrade South Island Electrical Infrastructure (GSFC)
- Utility Reliability Upgrades Mission Operations Complex (GSFC)
- Water Tower Repairs (LaRC)
- Compressor Station Upgrades, Phase 1 (LaRC)
- B1230 Renovations (LaRC)
- Replace Primary Electrical System Infrastructure B24 (GSFC)
- Construct Replacement Building 4221 (MSFC)
- Rehab Site-wide HPG He, GN and Air Distribution, Phase1 (SSC)
- Repair Bascule Bridge (SSC)
- Central Campus Phase 1 (KSC)
- Safety and Reliability Upgrades, KSC Institutional Power Systems, Phase 1 of 4 (KSC)
- Refurbish Environmental Control System (ECS), LC 39B (KSC)
- Construct Flame Deflector, LC 39B (KSC)
- Revitalize Power Systems, VAB Tower F (KSC)
- Launch Equipment Shop (K6-1247) Roof Replacement (KSC)
- Bldg. 831 Modifications and Storage Consolidation, VAFB (KSC)
- Parking Repair and Lighting, Bldg. 836/839/840, VAFB (KSC)
  Various modifications to VAB in support of SLS

NASA is planning to initiate several projects in FY 2019 to repair and revitalize its infrastructure. Included is the construction of the Aerospace Communications Facility at GRC, which replaces inadequate, inefficient, and failing facilities while investing in the centers' approved Master Plan, and providing consolidation, efficiency improvements, and long-term opportunity for other facility deconstruction. NASA plans to continue with repairs to restore the coastal shoreline with projects at KSC, and initiate shoreline protection project at WFF. Other significant projects include Repair Lewis Field Storm Sewer System, Phase 2 of 5 (GRC), and Revitalize Pressure & Propellant Distribution Systems (Site Wide, Phase 2 of 3) (MSFC).

NASA also plans to continue Energy Savings Investments that reduce energy cost and consumption in support of NASA's mission.

Institutional Discrete Construction of Facility Projects

Discrete Construction of Facilities projects have initial cost estimates of $10 million or greater.

Glenn Research Center

Aerospace Communications Facility
FY 2019 Estimate: $35.6 million

This project consists of constructing a 60,000 sq. ft. research facility consolidating multiple GRC Core Competency communications facilities into a single, state of the art building. The facility will house communications labs, antenna ranges, external antennas area; high bay area and hoteling/touchdown spaces. The project will demolish 4 existing facilities that experience envelope and system failures impacting productivity and mission readiness. Several of the buildings containing communications labs have experienced envelope failures of varying severity. Repairs are no longer effective at Building 7 which houses several antenna ranges. Water intrusion has damaged the structure, leading to debris falling on highly sensitive equipment. Water equipment has led to unhealthy work areas, impacting employee productivity and mission readiness.

This facility supports the SCaN Phase 3 Next Generation Architecture planetary network program for human exploration of Mars; Advanced Exploration Systems EVA Project supporting HEOMD'S Evolvable Mars Campaign (EMC); integration of Unmanned Aerial Systems (UAS) into the National Airspace (NAS) project. Timing of the construction is critically related to the SCaN Phase 3 program schedule to minimize any schedule delays or increased program costs. This facility also supports International Space Station (ISS), SLS and MPCV/Orion, and provides communication and navigation infrastructure and service for Lunar and Mars human missions.

Glenn Research Center

Repair Lewis Field Storm Sewer System, Phase 2
FY 2019 Estimate: $12.0 million; Total Construction Project Cost: $17.0 million (FY 2014 $5.0 million)

This project will consist of repairing and replacing the storm sewer piping associated with selected outfalls including Outfalls 004, 006, 025, 041. Repair branches and laterals associated with these outfalls and with nearby areas in which flooding is most prevalent.

The Center-wide Storm System impacts several buildings containing research and test labs that have experienced water failures of varying severity. Repairs are no longer effective and water intrusion has caused evacuation of facilities, damaged structures and infrastructure, leading to debris falling on highly sensitive equipment. Storm water in facilities has led to unhealthy work areas, impacting employee productivity and mission readiness for personnel and offices supporting International Space Station (ISS), SLS and MPCV/Orion, Subsonic air transportation system and Aeronautics Evaluation and Test Capabilities.

The original system is 70 years old is in poor condition and was not designed to adequately convey quantities of storm water imposed on the system. Rain and snow melt results in flooding several times per year in GRC Buildings.

Goddard Space Flight Center – Wallops Flight Facility

Shoreline Protection
FY 2019 Estimate: $24.6 million

This project consists of restoring the Wallops Island shoreline by replacing the eroded sand in order to maintain the 100-year storm damage reduction protection for the constructed launch assets on the island. It is anticipated that this project will minimize damages to WFF infrastructure during major Atlantic storm events (such as Hurricanes/Northeasters) over the next three to seven years. A past shoreline restoration project in 2012, for which 3,200,000 cubic yards of sand were dredged and placed on Wallops Island's beach, demonstrated the ability to protect infrastructure on the island during Hurricane Sandy, for which damages were minimal.

As documented by an official USACE Shoreline Monitoring Survey performed in Spring 2016, segments of the beach dune and beach berm have been reduced to near sea-level elevations, exposing the rock seawall to direct contact to the ocean. Wash-through on the seawall will start occurring and can eventually work its way through the structure, undermining the landward side of the wall. Through this action and the event of waves overtopping the wall during a storm, a significant amount of flood water can enter Wallops Island from the ocean side. Flooding has occurred at Wallops prior to the first beach replenishment due to this phenomenon. Additionally, some portions of the seawall further north are subject to stability issues when impacted by undermining. All of Wallops Island’s infrastructure is at risk once flooding occurs, particularly infrastructure at lower lying elevations.

Missions that are supported by WFF launch capabilities include Commercial Orbital Transportation Services (COTS) and numerous sounding rocket campaigns that are ongoing, the earliest two launches currently scheduled for May 2017 and an average of six to twelve launches a year for the near future. Multiple DOD missions are also planned from NASA WFF launch sites as well as commercial, state, and federal Unmanned Aerial Systems (UAS) missions from the new 3000 ft. North Island Airstrip.

Goddard Space Flight Center

Instrument Development Facility
FY 2019 Estimate: $2.0 million; Total Construction Project Cost: $43.3 million (FY 2018 $41.3 million)

This project constructs a state of the art Instrument Development Facility (IDF) to enable the development of required instruments and new technology for space flight mass spectroscopic measurements, replacing facilities whose age and configuration are impeding research and development efforts. NASA will use instruments developed in the IDF for studies of the chemistry of atmospheres and surfaces of distant planets, moons, and small bodies. These instruments have played significant roles on multiple recent missions (e.g., Mars Science Laboratory, Mars Atmosphere and Volatile Evolution Mission, and Lunar Atmosphere and Dust Environment Explorer).

Over the past 10 years, numerous significant flight instrument projects have expanded to multiple complex concurrent projects, exacerbating the inadequacy of the existing facilities. More significantly, advancing technology is critical for research and development activities targeting astrobiology, Mars instrument development, and other planetary instrument development.

Conditions in the existing facility are marginally adequate for limiting organic contamination as required for the Mars Organic Molecule Analyzer (MOMA) experiment under development for ExoMars, and likely inadequate for some technologies under development for potential future missions. These include potential Venus probe, Saturn probe, Ocean Worlds, and future Mars surface missions.

Supports Planetary Research.

Kennedy Space Center

Restore KSC Coastal Shoreline, Phase 2
FY 2019 Estimate: $15.0 million; Total Construction Project Cost: $31.0 million (FY 2018 $16.0 million)

This project is the second of two phases to construct a new sand dune along approximately the 4.5+ miles of KSC shoreline required to be restored and plant it with native dune vegetation.

Natural forces have severely eroded KSC's shoreline and interim fixes have not stabilized the shoreline long term. Storm activity including Hurricane Matthew resulted in loss of beach sand and sand dunes increasing significantly the risk of inland flooding, infrastructure loss and salt water intrusion. Breach of the sand dunes would cause a significant disruption of critical center-wide services and operational support for over a month.

The coastal dunes protect KSC's facilities and infrastructure including Launch Complex 39A and B from the impact of storm surge and inundation. This project will replace, repair, stabilize, and strengthen the coastal dunes deemed critical for protecting NASA's key launch complexes. This project will continue the test sand dunes (NASA's specialized dunes) constructed in 2014. The test sand dunes proved resilient and had no significant damage from Hurricane Matthew; whereas, the surrounding dunes were washed away.

The continuation of the construction of the sand dunes is important as absent completion of the dunes, during major storm events the KSC shoreline will experience dune breaches, resulting in inland flooding. KSC Center Management Council, chaired by the Center Director, has identified the KSC Shoreline Infrastructure risk as one of the top three worst risks for KSC. KSC will support numerous ISS cargo re-supply missions via the Commercial contracts, Commercial Crew missions, and at least seven SLS missions (AA-2, EM-2 through EM-7) using the launch pads at KSC over the next 10 years. If a dune breach occurred inland flooding would stop the missions. Shoreline protection is critical to protecting NASA's launch infrastructure. Breach of the sand dunes would cause a significant disruption of critical center-wide services and operational support for well over a month and operational cost impact of several million dollars during this period.

Supports all Kennedy core capabilities including SLS, Orion, and Commercial Space Flight.

Marshall Space Flight Center

Revitalize Pressure & Propellant Distribution Systems (Site Wide, Phase 2 of 3)

FY 2019 Estimate: $11.0 million; Total Construction Project Cost: $14.5 million (FY18 $3.5 million, Phase 3 To be Determined)

This project will focus on the center-wide distribution system and components with work in mechanical, civil/structural, electrical and architectural disciplines as required. It will also install gas meters throughout the system to enable identification of leaks and high use areas. This project will be planned, designed, and constructed incorporating sustainable/resilient design principles to reduce life-cycle costs, implement pollution prevention, minimize impact on natural resources, and maximize occupant health, safety, and productivity to the maximum extent possible.

The MSFC cross center distribution system provides high pressure air to the core research and test facilities supporting missions including International Space Station Payload operations Center and the Environmental Control and Life Support Systems (ECLSS) onboard ISS, Advanced Exploration Systems, Space Launch Systems, Multipurpose Crew Vehicle, Solar Probe Plus, Technology Demonstration Missions, Space Technologies Demonstrations, and Exploration Robotic Programs. Test requirements throughout the Center require that the high-pressure system be pressurized and ready for use 24 hours a day. Without this system, critical program milestones will be missed and it will impact the missions it supports. Portions of the system are over 40 years old and are corroding in various locations where the protective coating has broken down. There have been multiple failures and the condition of the pipe at failure locations has shown extensive corrosion. Probability of occurrence is known to be greater than 0.01 per operational opportunity. The system has experienced three pipe ruptures within a single calendar year, totaling over $100K in repair costs to the Center. Each failure of the gas distribution system resulted in major disruption of this critical operational support system for greater than 1 week. There is no backup distribution that can provide the pressures and quantities required. This project is the second phase of three to replace portions of MSFC's high pressure gas distribution system that has experienced piping failures due to corrosion.

Minor Revitalization and Construction of Facilities

FY 2019 Estimate: $57.2 million

Minor revitalization and construction of facilities projects have initial cost estimates between $1 million and $10 million. These projects consist of revitalizing and constructing facilities at various NASA center installations and government-owned industrial plants. Revitalization and modernization projects provide for the repair, modernization, and/or upgrade of facilities and collateral equipment. Repair projects restore facilities and components to a condition equivalent to the originally intended and designed capability. Repair and modernization work includes the equivalent replacement of utility systems and collateral equipment necessitated by incipient or actual breakdown. Modernization and upgrade projects include restoration of current functional capability and enhancement of the condition of a facility so it can accomplish its designated purpose, increase its functional capability, or meet new building, fire, and accessibility codes.

The minor revitalization and construction projects that comprise this request are of the highest priority, based on relative urgency, and expected return on investment. The focus is on projects that reduce building square footage or eliminate excess building systems, provide long-term savings, and reduce the Agency’s maintenance backlog. During the year, planned projects may change to accommodate changing priorities.

The minor projects listed below provide critical upgrades and repairs to eight NASA centers. Not funding these projects would cause direct cost, schedule, and personnel impacts to major NASA programs such as Orion and SLS with direct impacts to NASA’s commercial partners.

Armstrong Flight Research Center:

- Repair Flight Loads Lab Mechanical Systems

Glenn Research Center:

- Repair Facility Horizontal Communications Infrastructure, PBS
- GRC Repair Electrical Distribution Systems, Phase 3

Goddard Space Flight Center:

- Replace Secondary Low Voltage Electrical Systems

Johnson Space Center:

- Electrical Substation (B221)

Langley Research Center:

- Electrical Distribution System Upgrades, Langley Boulevard
- Potable Water Supply Upgrades, Part 2 of 2

Stennis Space Center:

- Repair/Replace Electrical Switchgear and Mitigation of Electrical Risk Site-wide

Energy Savings Investments

FY 2019 Estimate: $7.6 million

These important projects focus on improving systems efficiencies and reducing utility costs. The projects that comprise this request are of the highest priority based on expected return on investment or contribution to Federal energy mandates. The group of projects listed below collectively provides a 10.7-year simple payback period – the time required to recover the initial investment through annual energy cost avoidances.

Failure to implement these projects will affect NASA's ability to meet Executive Order 13693, "Planning for Federal Sustainability in the Next Decade," and will require NASA to continue to pay an estimated annual $1.2 million in utilities expenditures avoided by implementing these projects.

Johnson Space Center:

- Install Solar Photovoltaic Systems with Energy Storage, WSTF & Whites Sands Complex

Demolition of Facilities

FY 2019 Estimate: $20.0 million

NASA continues to meet its national fiduciary responsibilities, leveraging Agency retained assets to increase their functionality to support mission success while disposing of unneeded Federal real estate-increasing the use of under-utilized assets, minimizing operating costs, and improving energy efficiency.

INSTITUTIONAL COF

NASA will use the requested funding to eliminate inactive and obsolete facilities that are no longer required for NASA's Mission. Abandoned facilities pose potential safety and environmental liabilities and are eyesores at the Centers. The Agency must maintain these facilities at minimal levels to prevent increasing safety and environmental hazards, and these recurring maintenance costs impose a drain on the maintenance dollars available at the Centers. Demolishing these abandoned facilities allows the Agency to avoid non-productive operating costs required to keep abandoned facilities safe and secure. Demolition is the most cost-effective way to reduce the Agency deferred maintenance.

NASA identifies facilities for the demolition program through special studies to determine if the facility is required for current or future missions. Facilities that are no longer needed are included in a five-year demolition plan that sets project schedules based on last need, annual costs avoided, potential liability, and project execution factors.

Facility Planning and Design

FY 2019 Estimate: $30.8 million

NASA will continue to provide funding for advanced planning and design activities, special engineering studies, facility engineering research, preliminary engineering efforts required to initiate design-build projects, preparation of final designs, construction plans, specifications, and associated cost estimates associated with non-programmatic construction projects. This includes master planning, value engineering studies, design and construction management studies, facility operation and maintenance studies, condition-based maintenance studies, facilities utilization analyses, engineering support for facilities management systems, and capital leveraging research activities. Funding also supports participation in facilities-related professional engineering associations and organizations.

The facilities planning and design activity is crucial to implementing NASA's recapitalization strategy. These projects are necessary to make progress toward required sustainability, energy, and stewardship goals.

EXPLORATION COF

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**8.8**	**--**	**25.9**	**0.0**	**0.0**	**0.0**	**0.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

The B2 Test Stand at Stennis Space Center. This South East aspect shows the additional superstructure added to the stand to accommodate the height of the SLS Core Stage, as well as the completed tarmac in front of the stand.

Exploration CoF provides construction required to support SLS, Orion, and Exploration Ground Systems program activities. Funds required for the planning and design of out-year programmatic construction remain in the applicable program accounts.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

During FY 2017, NASA made tremendous progress transitioning facilities configured for the legacy Space Shuttle and Constellation programs to facilities configured to support the Space Launch System (SLS) and Orion programs for Exploration Missions.

At Kennedy Space Center (KSC), the Vehicle Assembly Building (VAB) and the Launch Complex 39B (LC-39B) are in the final stages of construction. In the VAB, Exploration Ground Systems (EGS) installed 20 platform levels (A-K) in High Bay 3. The installation included the mechanical, electrical and plumbing support systems, as well as the egress ramp access, new elevator landing platforms and facility utility subsystems to support SLS launch vehicle and Orion spacecraft processing. At LC-39B, modifications to the environmental control systems to support SLS and Orion, as well as the re-bricking the flame trench were completed. Fabrication and assembly of the new, all steel flame deflector components are in final stages of completion. Other significant work at LC-39B included construction of the liquid hydrogen liquid-gas separator tank and reinforcement of the catacomb roof structure that was necessary to accommodate the combined weight of the launch vehicle and its mobile launcher.

EXPLORATION COF

In FY 2017, EGS was also engaged in future planning and design efforts of KSC facilities to accommodate the processing of the Exploration Upper Stage (EUS) that will be used on the SLS Block-1B for EM-2. In High Bay 3 of VAB, concept studies and designs to accommodate the EUS began for the installation of a new environmental control system, installation of four new platforms and modifying eight of the existing platforms, as well as the addition of new fixed platforms in High Bay 4 also required for EUS processing. At LC-39B, EGS is actively addressing designs to increase the Liquid Hydrogen (LH2) capacity and modify the Emergency Egress System (EES). Additionally, EGS began the design effort for infrastructure upgrades at the Component Converter Facility (CCF) to increase operational efficiency and to augment the delivery of Helium and Nitrogen to LC-39B.

At Stennis Space Center (SSC), the SLS program completed major construction on the B-2 Test Stand in preparation for the SLS Green Run Testing. The new superstructure, necessary to accommodate the massive size of the SLS Core Stage, raised the height of the test stand to the 345 foot level. Other significant work on the B-2 in FY 2017 included installation of the cryogenic piping for the Liquid Oxygen and Liquid Hydrogen, the Fire Safety System piping and all of the piping necessary for Gaseous Helium, Nitrogen, and High Pressure Air. Additionally, the tarmac in front of the test stand was improved and strengthen to allow for the larger and heavier SLS Core Stage to roll off the barge prior to being lifted in to stand.

At the Michoud Assembly Facility (MAF), the SLS program continued making modifications to tooling and manufacturing in support SLS Core Stage production. In FY 2017, the program completed the repair of Chiller No 3 to improve reliability of the environmental control system in Building 103, the primary manufacturing facility for the SLS Core Stage. Additionally, the SLS program began the systematic removal and replacement of damaged roof purlins in Building 103 to maintain the structural integrity of the building roofing system. Other significant work at MAF included completing 8 out of 15 fan house repairs and rehabilitating the chilled water and steam distribution piping system by installing a 24-inch diameter supply and return pipes between the chiller plant located in Building 207 and Building 103.

At Marshall Space Flight Center (MSFC), the SLS program completed construction and activation of two structural test stands to support Space Launch System (SLS) Core Stage Qualification Testing. Test Stand 4693 will be used to test the Core Stage LH2 Tank and Test Stand 4697 will be used to test the Core Stage LOX Tank.

WORK IN PROGRESS IN FY 2018

At KSC, EGS will initiate the first two construction projects to upgrade and modify existing infrastructure to specifically support EM-2 launch requirements with SLS Block 1B launch vehicle. At LC-39B, a newly fabricated 1.25M gallon (est.) LH2 Dewar sphere, with associated vaporizer, flare stack and piping/valve system will be installed in the vicinity of the existing LH2 sphere. In the VAB, construction of a new Environmental Control System (ECS) will commence, as will the design for HB3 and HB4 platform installation to support the increased load demands and processing of the EUS.

At MAF, work will continue on modifications to Building 103 and Building 110 to support SLS Core Stage manufacturing. Construction planned to be completed in FY 2018 includes: Building 103 Final Integration (Fall Protection), phase 1 of the fan house and substation structural repairs in Building 103, rehabilitating the chilled water and steam distribution piping, replacing and rehabilitating Substations 20A, 43, 63 and 64, phase 2 of replacing the roof purlins in Building 103. Additionally, SLS plans to begin work on replacing electrical substation No. 1, phase 2 repairs of fan houses and substation structural supports in Building 103, the second phase of roof purlin replacement Building 103 and repairing the roof of Building 102.

At MSFC, the two structural test stands will be completely activated and operational. Minor open work after acceptance will be completed, including the installation of egress lighting on the roof of TS4693 and additional engineering documentation from the Architecture & Engineering (A&E) firm.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

At KSC, EGS will continue to focus on SLS Block 1 infrastructure requirements for EM-2
At LC-39B, the program will begin construction of the emergency egress system (EES). The EES provides a safe haven for crew emergency egress and evacuation during prelaunch activities. Design of additional platforms in VAB high bay 3 and 4 will also continue. Additionally, EGS will begin one minor construction project in FY 2019 to upgrade the Rotational Processing Surge Facility (RPSF) fire projection system.

At MAF, work is expected to initiate on minor construction projects to rehabilitate the East Master Substation, replace electrical Substation 21, phase 1 to rehabilitate the IWTF Tank and process system components and phase 1 to rehabilitate the facility's drainage system Ph 1. Work will continue on replacing electrical Substation No. 1, second phase of repairing fan houses and substation structural support, phase 2 of replacing the roof purlins in Building 103 and repairing the roof on Building 102.

Exploration Discrete Construction of Facilities Projects

Kennedy Space Center

Modifications for SLS Block 1B (EUS)

FY 2019 Estimate: $13.3 million; Total Construction Project Cost: $206.0 million (FY 2020 $80.3 million, FY 2021 $18.9 million, and FY 2022 $3.5 million)

KSC project that modifies designated facility systems in the Vehicle Assembly Building (VAB), Launch Complex 39B (Pad-B), and Convertor Compressor Facility (CCF) to enable Space Launch System (SLS) Exploration Upper Stage (EUS) processing and launch operations. As SLS technical requirements mature, EGS may need to modify scope within work elements of this project.

The upgrades reconfigure of KSC facilities from previous shuttle configurations to support new SLS vehicle processing con, while increasing the life safety of the facilities and operational efficiency. The VAB modifications reconfigure the high bay to process, integrate and assemble the SLS launch vehicle. The Pad-B modifications will support SLS, Orion and other Launch vehicles; as they update the deteriorated 40 year old structure and systems. The CCF modifications increase the peak nitrogen and helium flows required for EUS support, while replacing the Apollo facility systems with modern technology.

These repairs and modifications must be completed in time to support future SLS launches because there are no other facilities that have the size or capabilities necessary to support SLS assembly operations.

Failure to implement this project will seriously impact NASA's ability to transition and sustain the use of this launch complex to support SLS.

Supports SLS, Orion, and other launch vehicles.

Minor Revitalization and Construction of Facilities

FY 2019 Estimate: $12.6 million

These projects provide for the repair, modernization, or upgrade of facilities and collateral equipment required by Exploration activities. Repair projects restore facilities and components to a condition substantially equivalent to the originally intended and designed capability. Repair and modernization work includes the substantially equivalent replacement of utility systems and collateral equipment necessitated by incipient or actual breakdown. Modernization and upgrade projects include both restoration of current functional capability and enhancement of the condition of a facility, so that it can more effectively serve its designated purpose, increase its functional capability, or so that it can meet new building, fire, and accessibility codes.

The minor project below provide critical investments to support refurbishment of infrastructure to support the ensure NFPA compliance at KSC. During the year, rearrangement of priorities may be necessary, which may cause a change in some of the items to be accomplished.

Kennedy Space Center:

- Rapid Processing and Surge Protection Facility (RPSF) Fire Protection System Upgrade

Michoud Assembly Facility:

- Rehab East Master Substation
- Replace Substation 21
- Rehab IWTF Tank and Process System Components Phase 1
- Rehab Drainage System Phase 1

SPACE OPERATIONS COF

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**36.7**	**--**	**18.9**	**0.0**	**0.0**	**0.0**	**0.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

View of the recently completed and operational 34-meter Beam Wage Guide antenna DSS- 36 in Canberra, Australia.

Space Operations CoF provides construction to support Space Communication and Navigation (SCaN), the ISS program and Launch Services Program (LSP). Funds required for the planning and design of out-year programmatic construction remain in the applicable program accounts.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

The completion of Deep Space Station (DSS)-36 in Canberra, AU shifted the focus of the DSN Aperture Enhancement Project (DAEP) toward the construction of the next two 34-meter Beam Wave Guide antennas in Madrid. In early FY 2017 the excavation phase at Madrid was completed, allowing for the Pedestal construction phase to begin. In order to meet the operational need date for NASA mission support, both antenna pedestals are being constructed simultaneously. In Australia, the Deep Space network (DSN) completed the DAEP facilities support phase for both DSS-35 and DSS-36 Beam Wave Guide antennas.

At Goldstone Deep Space Communication Complex (GDSCC), a minor construction project to install seismic upgrades to various buildings brought existing buildings and other support assets into compliance for safety and seismic requirements. Due to efficiencies in the project, additional GDSCC buildings are being evaluated for seismic upgrades.

Throughout the Network, each complex also experienced improvements at their facilities with the 34m BWG Antenna HVAC chiller replacement project that boosted the reliability needed for cooling the transmitters at the antenna stations. This project is near completion with the final procurement of the water cooling, purification, and storage subsystems necessary for protecting and increasing the reliability of the new chiller systems.

Additionally, the minor construction project to replace the Beam Wage Guide azimuth tracks in 34m Subnet is in progress with the fabrication track slated for DSS-13. These much-needed improvements will ensure the reliability of the antennas.

The Launch Services Program (LSP) commenced three minor construction projects in FY 2017. Two of the minor construction projects were at the Vandenberg Air Force Base (VAFB) to modify Building 831 storage consolidation and repairing the pavement of NASA Facilities at VAFB. The third minor construction project for LSP was at KSC and Cape Canaveral Air Force Facility to replace the Chillers and Boilers at Hangar AE and the PHSF.

Rocket Propulsion Test Program (RPT) continued a minor construction project that relocates the Fluid Component Cleaning Facility from the Stennis Space Center (SSC) to the Michoud Assembly Facility. The scope of this minor construction includes procuring and installing a modular clean room in Building 103 at MAF. RPT also commenced a minor construction project in the In-Space Propulsion (ISP) Facility at Plum Brook Station to refurbish and re-constitute the process steam capability sufficiently to enable hot-fire testing of a 30,000lb class rocket engine for up to 300 seconds.

At KSC, the 21st Century Launch Complex provided additional infrastructure upgrades, including the installation of a new HVAC system and roof replacement at the KSC Launch Equipment Shop (LES). LES provides the center with off-nominal manufacturing capability to ensure successful processing of flight hardware.

WORK IN PROGRESS IN FY 2018

Focus for FY 2018, is the continued support and progress for SCaN's multi-year funded discrete project to construct the two new 34m Beam Wave Guide (BWG) Deep Space Station (DSS) antennas, DSS-56 and DSS-53 at Madrid. Supporting subcontracts have been awarded and are moving forward. Steel fabrication at lower-tier contractors is escalating, with projections of starting the on-site assembly work in early FY 2018. Antenna RF panels, mirrors, and sub-reflectors are also in production.

Several Minor projects will continue towards completion in 2018. For the DSN Beam Wave Guide Subnet, both, the BWG Antenna Chiller replacement project and the BWG Azimuth Track replacement project are planned to be completed. In Australia, the site wide uninterrupted power system (UPS) installation project is also planned to be completed. In Madrid, the Antenna Apron and Subsoil remediation project will continue as planned.

LSP will continue to work on three minor construction projects that commenced in FY 2017, modification of Building 831 storage consolidation, repairing the pavement of NASA Facilities at VAFB and replacing the Chillers and Boilers at Hangar AE and the PHSF at KSC and Cape Canaveral Air Force Facility. In addition, LSP will commence a new minor construction project at VAFB to improve the energy efficiency in Buildings 836 and 840.

RPT is scheduled to finish the installation of the modular clean room in Building 103 at MAF, completing the relocation of the Fluid Component Cleaning Facility at MAF. Additionally, RPT will continue the minor construction project in the ISP Facility at Plum Brook Station to partially re-activate the process steam system sufficiently to enable hot-fire testing of a 30,000lb class rocket for up to 300 seconds.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

FY 2019 will be a busy year for the DSN for both discrete and minor construction projects. SCaN will continue its efforts for the construction of the two new 34-meter Beam Wave Guide (BWG) Deep Space Station (DSS) Antennas at the Madrid Complex. Phase III of the DAEP, will see the start of construction for another 34m Beam Wave Guide antenna at Goldstone, California, DSS-23.

In FY 2019, four additional minor construction projects are planned throughout the DSN complexes. At the Canberra Complex, upgrades to various HVAC systems for occupied support operations buildings will begin. Additionally, pre-1970 substation equipment at DSS-43 will be replaced with modern and maintainable distribution equipment. Both efforts will help to bring the Canberra facility to modern operating standards for safety and reliability. In Madrid, the upgrade switchgear and protection integration project will provide an upgrade of the powerhouse switchgear and controls. Current system components contain friable asbestos and must be removed due to in-country safety regulations. Lastly, the DSN network will be replacing the antiquated cooling towers in support of the 70m antennas' new transmitter design. The new transmitter design with greater performance requirements make this project a necessity.

LSP will commence a minor construction project at VAFB to install a new HVAC in Building 840. The project consists of installing an integrated heating ventilation and air conditioning (HVAC) system for the entire 25,000 ft^2 building.

Space Operations Discrete Construction of Facility Projects

Jet Propulsion Laboratory

DAEP Phase II: Construction of 34 Meter Beam Wave Guide Antennas – Madrid

Location: Madrid Deep Space Communications Complex, Spain.
FY 2019 Construction Estimate: $1.5 million, Total Project FY 2015 to FY 2019 is $57.75 million.

This project constructs two (2) new 34-meter beam wave guide (BWG) antennas at the Madrid Deep Space Communications Complex (MDSCC), provides for the construction of DSS-56 and DSS-53.

The project is divided into five contracts: excavation, pedestal, antenna construction, servo system, and antenna related site facilities. The funding for fiscal year 2019 is $1.5 million of the total $57.75 million.

The project includes the fabrication and installation of the antenna structures, panels, gearboxes, bearings, electric drives, encoders, beam wave guide mirrors, sub-reflectors and positioners, and related servomotors. The project also includes the construction of the pedestals, as well as all facilities in and around the antennas, including the paved access roads, trenches, drainage, flood control devices, water main and distribution system, antenna apron, perimeter security fence, HVAC systems, electrical power distribution, fire detection and suppression system, and surveillance system assembly.

Basis of Need

The construction of these antennas is planned as Phase II of the SCaN DSN Aperture Enhancement Project (DAEP) and was originally scheduled to begin after completion of the third optioned antenna at Canberra, however two existing antennas at Madrid are showing concrete degradation in their pedestals; DSS-63 70-meter and DSS-54 34-meter, it was decided to begin construction of the two 34-meter antennas at Madrid in FY15 as a contingency against future long-term maintenance downtimes of the existing 70-meter and 34-meter antennas.

Jet Propulsion Laboratory

AEP Phase III: Construction of 34 Meter Beam Wave Guide Antenna - Goldstone

Location: Goldstone Deep Space Communications Complex, California
FY 2019 Construction Estimate: $4.5 million, Total Project FY 2019 to FY 2022 is $32.0 million.

This project constructs one (1) new 34-meter beam wave guide (BWG) antenna at the Goldstone Deep Space Communications Complex (GDSCC); provides for the construction of DSS-23.

The project will be issued as a single Primary Subcontract to include excavation, pedestal, antenna construction, servo system, and antenna related site facilities. The funding for fiscal year 2019 is $4.5 million of the estimated total of $32.0 million.

The project will be managed as was the DAEP Phase I in Canberra.

Basis of Need

The construction of this antenna is planned as Phase III of the SCaN DSN Aperture Enhancement Project (DAEP) and is scheduled to begin towards the completion of the Madrid antennas.

SCaN has recently shown interested in developing a Hybrid Optical/RF antenna design for the DSN. Ideally, Goldstone, with its location and optimal weather conditions has been identified as the best site for this effort. Antenna DSS-23 will be an RF Antenna with the possibility for modification.

Minor Revitalization and Construction of Facilities

FY 2019 Estimate: $12.9 million

These projects provide for the repair, modernization, or upgrade of facilities and collateral equipment required by Space Operations activities. Repair projects restore facilities and components to a condition substantially equivalent to the originally intended and designed capability. Repair and modernization work includes the substantially equivalent replacement of utility systems and collateral equipment necessitated by incipient or actual breakdown. Modernization and upgrade projects include both restoration of current functional capability and enhancement of the condition of a facility, so that it can more effectively serve its designated purpose, increase its functional capability, or so that it can meet new building, fire, and accessibility codes.

The FY 2019 request includes one minor construction project for the Launch Services Program (LSP) for sustainability upgrades that will improve the energy efficiency of Buildings 836 and 840 at Vandenberg

Air Force Base (VAFB) launch complex. The SCaN program will have four minor construction projects to upgrades to various HVAC systems at Canberra to support operations buildings; replace the pre-1970 substation equipment at DSS-43 with modern and maintainable distribution equipment; upgrade Switchgear & Protection Integration at Madrid; and replacing the cooling towers in support of the 70m antennas.

Kennedy Space Center:

- Install HVAC System B-840 at Vandenberg Air Force Base

Jet Propulsion Laboratory:

- Operations Building HVAC Upgrades, Canberra
- Switchgear Upgrade and Protection Integration, Madrid
- Replace 70m Antenna Cooling Towers
- DSS-43, US-1, US-2 Servo Starter Replacement, Canberra

SCIENCE COF

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**2.7**	**--**	**9.6**	**0.0**	**0.0**	**0.0**	**0.0**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Artist's rendering of the fully populated modular computing facility, which will house energy efficient supercomputing modules.

Science CoF typically provides construction required to support NASA's programs in Earth Science, Planetary Science, Astrophysics, and Heliophysics. However, it also includes construction for NASA's High End Computing Capability (HECC) Program, which the Science Mission Directorate, as the biggest user, manages for the Agency.

Construction for HECC directly supports the Aeronautics, Human Exploration and Operations, Science, and Space Technology Missions. Funds required for the planning and design of out-year programmatic construction remain in the applicable program accounts.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ACHIEVEMENTS IN FY 2017

In FY 2017, NASA procured a second modular supercomputing unit for the proof-of-concept prototype for the Modular Supercomputing Facility (MSF) at ARC. Rather than meeting computing requirements through the expansion of capability within conventional facilities, this pilot project constructed lower cost modular container-based capability adjacent to the Advanced Supercomputing Facility at ARC. The second module also tests the inter-connectivity with the first module such that the two modules may be integrated as a single supercomputer to solve larger scientific and technical problems together. The combined capability is measured at 4.78 petaflops of peak performance. The prototype demonstrated the feasibility of new energy efficient and water-conserving modular computing technology, enabling the increase of NASA’s supercomputing capability with minimal impact on limited energy and water resources.

WORK IN PROGRESS IN FY 2018

In FY 2018, NASA will begin construction of the MSF at Ames Research Center, based on the successful proof-of-concept prototype completed in FY 2016-2017. The FY 2018 work will provide the infrastructure and utilities required to support the modular container-based capability. When complete, the project will ensure flexibility to adjust for fast-changing technology with minimal risk, and will provide the supercomputing capability necessary to meet NASA's mission requirements.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

In FY 2019, NASA will proceed with the Replace/Refurbish Laboratory Infrastructure (Bldg. N239) Project at the Ames Research Center, the Asteroid Sample and Advanced Curation Facility at Johnson Space Center, along with the parallel processing of two large balloon payloads at Wanaka, New Zealand.

Minor Revitalization and Construction of Facilities

FY 2019 Estimate: $9.6 million

These projects provide for the repair, modernization, or upgrade of facilities and collateral equipment required by Science activities. Repair projects restore facilities and components to a condition substantially equivalent to the originally intended and designed capability. Repair and modernization work includes the substantially equivalent replacement of utility systems and collateral equipment necessitated by incipient or actual breakdown. Modernization and upgrade projects include both restoration of current functional capability and enhancement of the condition of a facility, so that it can more effectively serve its designated purpose, increase its functional capability, or so that it can meet new building, fire, and accessibility codes.

The FY 2019 request includes a minor construction project in support of NASA's strategic long-range, mid-latitude superpressure balloon operations in Wanaka, New Zealand, providing for parallel processing of two large balloon payloads during the annual campaign, in response to high science community interest. The request also includes minor projects that will modernize outdated and non-compliant laboratories on the 3rd and 4th floors of Building N239 at ARC, as well as convert existing laboratory and office space at JSC for precision cleaning and curation. The JSC project is critical to the development, testing, and refinement of organic and microbiological contamination control procedures and precision cleaning techniques required for future astromaterial samples, most immediately, asteroid samples due to arrive at NASA’s facilities in 2021 and 2023, respectively .

Ames Research Center:

- Replace/Refurbish Laboratory Infrastructure, Building N239

SCIENCE COF

Johnson Space Center:

- Asteroid Sample and Advanced Curation Facility

Goddard Space Flight Center:

- Balloon Payload Facility, Wanaka, New Zealand

ENVIRONMENTAL COMPLIANCE AND RESTORATION

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	70.2	--	82.9	82.9	82.9	82.9	82.9

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Remediation of contamination in the groundwater at MAF. Electrical current is applied through electrodes driven into the ground and the contaminated soils and groundwater are heated. The volatilized contaminants are removed through vacuum extraction.

NASA's ECR program cleans up hazardous materials and wastes released to the surface or groundwater at NASA installations, NASA-owned industrial plants supporting NASA activities, current or former sites where NASA operations have contributed to environmental problems, and other sites where the Agency is legally obligated to address hazardous pollutants. ECR program activities include projects, studies, assessments, investigations, sampling, plans, designs, construction, related engineering, program support, monitoring, and regulatory Agency oversight.

Funding also covers land acquisitions required to ensure operation of remedial treatment processes and sites as part of remediation and cleanup measures.

For additional information about NASA's ECR program, go to: http://www.nasa.gov/offices/emd/home/ecr.html.

EXPLANATION OF MAJOR CHANGES IN FY 2019

None.

ENVIRONMENTAL COMPLIANCE AND RESTORATION

ACHIEVEMENTS IN FY 2017

NASA's ECR program includes cleanup activities at all NASA centers, with priority given to protecting human health and the environment in conformance with Environmental Protection Agency and state regulatory agreements and requirements. NASA accomplished the following notable restoration activities in FY 2017:

- SSFL continued demolition of buildings not associated with test stands and development of work plans for soil cleanup, continued soil, and groundwater cleanup treatability studies, completed groundwater field investigations, operated groundwater treatment system and conducted long-term monitoring of groundwater. Cultural resource actions were continued per the Programmatic Agreement with the State Historic Preservation Office, Native Americans, and consulting parties;
- MSFC completed soil cleanup at petroleum sites and developed designs for the Industrial Sewer operable unit remedial action and monitoring/ characterization of groundwater;
- GRC continued decontamination and decommission of the cyclotron building under NRC license termination;
- MAF began the thermal treatment pilot scale remediation of groundwater at the former rinse water impoundments;
- WSTF continued to operate the plume front and mid-plume front treatment systems to capture and treat contaminated groundwater. They also continued source area investigations and closure activities of the sewage lagoon;
- KSC installed several new groundwater treatment systems, completed extensive contaminated soil removal at various sites, continued sampling of over 400 monitoring wells, and continued operations of existing groundwater cleanup systems;
- JPL continued to operate and maintain systems to clean up contaminated groundwater emanating from the laboratory, and operations and system upgrades to the Lincoln Avenue and Monk Hill drinking water treatment systems.

WORK IN PROGRESS IN FY 2018

NASA is continuing its commitment to restoration by executing the following activities in FY 2018:

- SSFL will continue to demolish structures in areas not associated with the Test Stands, submit cleanup plans for soil and groundwater, and continue operations of the groundwater treatment system and long-term monitoring of groundwater. Cultural resource actions will continue per the Programmatic Agreement with the State Historic Preservation Office, Native Americans, and consulting parties;
- GRC will continue decontamination and decommission of the cyclotron building under NRC license termination;
- KSC will continued investigation and cleanup of groundwater and soil contamination. Activities planned include the installation of new groundwater treatment systems, removal of contaminated soils, investigation of additional sites for potential contamination, continued sampling of over 400 monitoring wells, and continued operations of existing groundwater cleanup systems;
- ARC will begin landfill remediation and final closure per Federal Facilities Agreement;
- MSFC will begin cleanup of the Industrial Sewer operable unit and monitoring/ characterization of groundwater;

ENVIRONMENTAL COMPLIANCE AND RESTORATION

- WSTF will continue to operate the plume front and mid-plume front treatment systems to capture and treat contaminated groundwater and continue source area investigations and closure activities of the sewage lagoon; and
- Continue operations of treatment systems and monitoring at AFRC, GSFC, LaRC, MAF, SSC, and WFF.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

Key projects and achievements planned for the FY 2019 request include:

- $10.9 million for the continued cleanup of ground water contamination and investigation of soil contamination at WSTF, to include completion of closure activities, implementation of source area facility investigations, long-term monitoring of groundwater, and continued operation of the plume front and mid-plume ground water treatment systems;
- $9.2 million for the continued investigation and cleanup of groundwater and soil contamination at KSC under State of Florida requirements. Key activities planned include the installation of new groundwater treatment systems, removal of contaminated soils, investigation of additional sites for potential contamination, continued sampling of over 400 monitoring wells, and continued operations of existing groundwater cleanup systems;
- $7.5 million to operate and maintain systems to clean up contaminated groundwater emanating from JPL and continued operations of the Lincoln Avenue and Monk Hill drinking water treatment systems; and
- $39.2 million for demolition, cleanup of contaminated soils, continued operation of groundwater treatment systems, and continued long term monitoring of groundwater at SSFL in accordance with the State of California. Cultural resource actions will continue per the Programmatic Agreement with the State Historic Preservation Office, Native Americans, and consulting parties.

Program Elements

RESTORATION

Restoration projects address cleanup liabilities at all NASA centers and component facilities. As of the start of FY 2018, known liabilities totaled $1.4 billion with many of the individual cleanup projects estimated to take more than 30 years to complete. NASA policy is to address these liabilities using a “worst first” approach to ensure protection of human health and the environment and to facilitate mission readiness. Plans for FY 2019 are based on a prioritized, risk-based approach for incrementally addressing NASA’s cleanup portfolio. Projects are ranked according to the relative urgency and the potential health and safety hazards related to each individual cleanup. As studies, assessments, investigations, plans, regulatory approvals, and designs progress, and as new discoveries or regulatory requirements change, NASA may adjust program priorities.

ENVIRONMENTAL COMPLIANCE AND RESTORATION

ENVIRONMENTAL COMPLIANCE AND FUNCTIONAL LEADERSHIP

Environmental Compliance and Functional Leadership projects invest in environmental methods and risk reduction practices that ensure NASA may continue to carry out its scientific and engineering missions. This includes methodologies for sustainably reducing energy intensity and greenhouse gas emissions, and supporting operational activities by ensuring that advances in chemical risk management are incorporated early in mission design phases.

INSPECTOR GENERAL

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**37.9**	**37.6**	**39.3**	**39.3**	**39.3**	**39.3**	**39.3**

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

INSPECTOR GENERAL

FY 2019 Budget

Budget Authority (in $ millions)	Actual FY 2017	CR FY 2018	Request FY 2019	Notional FY 2020	FY 2021	FY 2022	FY 2023
Total Budget	**37.9**	**37.6**	**39.3**	**39.3**	**39.3**	**39.3**	**39.3**
Change from FY 2018			**1.7**				
Percentage change from FY 2018			**4.5%**				

FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency's current FY 2017 Operating Plan.

A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

For FY 2019, the NASA Office of Inspector General (OIG) requests $39.3 million to support the work of auditors, investigators, analysts, specialists, lawyers, and support staff located at NASA Headquarters in Washington, DC, and 12 other locations throughout the United States.

The OIG conducts audits, investigations, and reviews of NASA programs to prevent and detect fraud, waste, abuse, and mismanagement and to assist NASA management in promoting economy, efficiency, and effectiveness in its programs and operations. Our operational offices are the Office of Audits (OA) and the Office of Investigations (OI).

OA conducts independent and objective audits of NASA programs, projects, operations, and contractor activities, and oversees the work of the independent public accounting firm that conducts the annual audit of NASA's financial statements. In its work, OA targets high-risk areas and NASA's top management challenges. OIG audits provide independent assessments and actionable recommendations that help NASA achieve its space exploration, scientific, and aeronautics research missions.

OI pursues allegations of cybercrime, fraud, waste, abuse, and misconduct related to NASA programs, projects, personnel, operations, and resources. OI refers its findings to the Department of Justice for criminal prosecution and civil litigation or to NASA management for administrative action. Through its investigations, OI develops recommendations to reduce the Agency's vulnerability to criminal activity or administrative inefficiency. Given that NASA spends approximately 83 percent of its budget on contracts and grants, OI's caseload includes investigations of suspected false claims submitted by NASA contractors, product substitution and counterfeit parts, and conflict of interest cases that involve NASA employees who place private gain before public service.

EXPLANATION OF MAJOR CHANGES IN FY 2019

No major changes.

INSPECTOR GENERAL

ACHIEVEMENTS IN FY 2017

In FY 2017, the OIG issued 15 audit products that contained 88 recommendations for improvement and identified approximately $97.9 million in potential savings for NASA. Audit products included reports examining NASA's:

- Plans for human exploration beyond low Earth orbit;
- Efforts to "rightsize" workforce, facilities, and other supporting assets;
- Management of its existing spacesuit fleet and development of next-generation spacesuits;
- Earth Science Mission portfolio;
- Industrial control system security within the Agency's critical and supporting infrastructure; and
- Management of the Mars 2020 Rover Program.

In FY 2017, OI investigated a wide variety of criminal and administrative matters involving procurement fraud, theft, counterfeit parts, ethics violations, and computer intrusions leading to more than $18 million in criminal, civil, and administrative penalties and settlements. Approximately $2 million of these funds were returned directly to NASA. Overall, OI's efforts in FY 2017 resulted in 30 indictments, 15 convictions, 3 civil settlements, 39 administrative actions, and 24 suspensions or debarments.

Examples of OI's work over the past year include:

- An investigation of fraud committed by Educational Advancement Alliance, Inc., (EAA) and its president ended in the convictions and sentencing of the president, former Pennsylvania Congressman Chaka Fattah, and several associates. The organization received a series of Federal grants including a $1.8 million grant from NASA to promote science, technology, engineering, and mathematics education. The investigation revealed that EAA improperly used $100,000 of NASA grant money to pay a campaign debt on Congressman Fattah's behalf. In June 2016, a Federal jury convicted the Congressman and his associates of taking part in a racketeering conspiracy intended to further their political and financial interests by misappropriating Federal, charitable, and campaign funds. In December 2016, the Congressman was sentenced to 10 years of imprisonment, was ordered to pay $614,000 in restitution, of which $100,000 will be returned to NASA. The company president was sentenced to 2 years of imprisonment. In May 2017, Fattah was debarred from doing work with the Federal Government for 16 years. The OIG assisted the Federal Bureau of Investigation and the Internal Revenue Service in the investigation.

- As a result of an investigation conducted by the NASA OIG, the Defense Contract Management Agency, Defense Contract Audit Agency, and the Defense Criminal Investigative Service, a Nevada aerospace company agreed to pay $14.9 million to settle allegations it violated the Federal False Claims Act by knowingly misclassifying certain costs and causing various Government agencies to pay inflated contract overhead rates.

- In January 2017, a Los Angeles, California, contractor was sentenced to 2 years of imprisonment and a $7,500 fine stemming from charges of conspiracy and providing illegal gratuities. From 2008 through 2012, the company co-owner, along with his business partner, conspired to provide gratuities to approximately 70 Government purchase cardholders in exchange for their continued business. The company owners paid approximately $42,590 in gratuities, which yielded an estimated $3 million in return business. The co-conspirator was sentenced to 3 years of probation.

- Investigative efforts by the OIG helped prove a $5.1 million claim against NASA by a Cleveland, Ohio, construction contractor was without merit. The investigation revealed the prime contractor greatly exceeded subcontracting limitations and failed to hire qualified safety professionals for a construction project at Glenn Research Center. This contributed to a serious injury that was at the center of the construction company’s claim.

- As the result of an investigation conducted by the NASA OIG, the U.S. Air Force Office of Special Investigations, and the Defense Criminal Investigative Service, the co-owner of a Beavercreek, Ohio, firm pled guilty to one count of conspiracy to defraud the U.S. Government after falsely claiming disabled veteran status. He was sentenced to 3 years of probation and ordered to pay a $50,000 fine. In June 2017, a co-owner of the firm was indicted on one count of conspiracy to defraud the U.S. Government for the same offense.

- Following a joint investigation by the NASA OIG and the Federal Bureau of Investigation, a U.S. citizen was indicted in January 2017 for conspiracy to commit unauthorized computer access. The subject was part of a hacking group that claimed to have taken control of a NASA drone. An investigation revealed the group never controlled the drone and only had access to publicly available data they leveraged to perpetrate the hoax.

- In April 2017, a former Stennis Space Center contractor employee was indicted on two counts of possession of child pornography. In May 2017, a grand jury returned a superseding indictment of two counts of possession of child pornography and one count of receipt of child pornography. The subject pled guilty and was sentenced to 19 years 8 months and ordered to pay $119,500 in restitution.

WORK IN PROGRESS IN FY 2018

In the first six months of FY 2018, the OIG has issued audit reports examining NASA’s efforts to improve Agency information technology (IT) governance, management of spare parts for flight projects, and compliance and reporting requirements under the 2014 Digital Accountability and Transparency Act. During the remainder of the fiscal year, we will continue to conduct audits, reviews, and investigations of NASA programs and operations to prevent and detect fraud, waste, abuse, and mismanagement and to assist NASA in promoting economy, efficiency, and effectiveness. Projects on which our auditors are currently working include NASA’s commercial cargo contracts; an assessment of the Agency’s IT security operations center; IT supply chain management; and oversight of the Surface Water and Topography (SWOT) satellite mission.

Ongoing OI work includes proactive initiatives designed to identify acquisition and procurement fraud schemes. Additionally, representatives from both OI and OA are working together to use the OIG’s sophisticated data analytics capabilities to help identify indicators of potential fraudulent activity.

KEY ACHIEVEMENTS PLANNED FOR FY 2019

Going forward, the OIG will continue to focus its audit work on NASA's top management and performance challenges. In a November 2017 report, we listed those challenges as:

- Deep Space Exploration;
- NASA's Science Portfolio;
- Information Technology Governance and Security;
- Aging Infrastructure and Facilities; and
- Contracting and Grants.

The OIG's FY 2019 request is $39.3 million, and includes the following:

- $33.2M (85 percent) to fund personnel and related costs, including salaries, benefits, monetary awards, worker's compensation, permanent change of station costs, and Government contributions for Social Security, Medicare, health and life insurance, retirement, and the Thrift Savings Plan. Salaries include the required additional 25 percent law enforcement availability pay for criminal investigators.
- $2.5M (6 percent) to fund the statutorily required annual audit of the Agency's financial statements.
- $0.9M (2 percent) to fund travel, per diem, and related expenses.
- $2.7M (7 percent) to fund equipment, training, government vehicles, special equipment for criminal investigators, transit subsidies, and information technology equipment unique to the OIG.[1]

In Public Law 115-31, Consolidated Appropriations Act, 2017, the OIG received $500,000 of 2-year funding to allow us to execute our budget in alignment with NASA's end-of-year close-out procedures. For FY 2019, we are requesting that all funding be deemed 2-year funding. This change is consistent with NASA's appropriations – that is, the OIG is the only component of NASA lacking 2-year budget authority – and will allow the OIG to streamline its financial, procurement, and other year-end processes within NASA's centralized systems to more efficiently carry out its oversight mission.

1 *This number includes $500,000 for staff training and $100,000 to support the Council of Inspectors General on Economy and Efficiency (CIGIE). In accordance with Public Law 110-409, the Inspector General Reform Act of 2008, the Inspector General certifies that these amounts are sufficient to satisfy all training requirements and contributions to CIGIE.*

Supporting Data

FUNDS DISTRIBUTION BY INSTALLATION

FUNDS BY MISSION BY NASA CENTER

Budget Authority ($ in millions)	FY 2019*
Deep Space Exploration Systems	27.8
Exploration Research and Technology	56.7
LEO and Spaceflight Operations	38.8
Science	191.1
Aeronautics	111.5
Education	0.0
Safety, Security, and Mission Services	204.4
Construction and Environmental Compliance and Restoration	4.8
Ames Research Center (ARC) Total	**635.1**
Deep Space Exploration Systems	15.0
Exploration Research and Technology	4.4
LEO and Spaceflight Operations	0.3
Science	59.4
Aeronautics	146.1
Education	0.0
Safety, Security, and Mission Services	59.6
Construction and Environmental Compliance and Restoration	7.2
Armstrong Flight Research Center (AFRC) Total	**292.1**
Deep Space Exploration Systems	115.4
Exploration Research and Technology	80.7
LEO and Spaceflight Operations	64.5
Science	32.4
Aeronautics	144.9
Education	0.0
Safety, Security, and Mission Services	210.7
Construction and Environmental Compliance and Restoration	62.8
Glenn Research Center (GRC) Total	**711.5**
Deep Space Exploration Systems	2.0
Exploration Research and Technology	65.8
LEO and Spaceflight Operations	185.5
Science	2,075.9
Aeronautics	14.0
Education	0.0
Safety, Security, and Mission Services	399.6
Construction and Environmental Compliance and Restoration	34.9
Goddard Space Flight Center (GSFC) Total	**2,777.7**

FUNDS DISTRIBUTION BY INSTALLATION

Budget Authority ($ in millions)	FY 2019*
Deep Space Exploration Systems	0.5
Exploration Research and Technology	44.8
LEO and Spaceflight Operations	186.0
Science	1,413.7
Education	0.0
Safety, Security, and Mission Services	14.8
Construction and Environmental Compliance and Restoration	24.4
Jet Propulsion Laboratory (JPL) Total	**1,684.2**
Deep Space Exploration Systems	1,257.3
Exploration Research and Technology	139.8
LEO and Spaceflight Operations	3,360.3
Science	24.2
Education	0.0
Safety, Security, and Mission Services	350.5
Construction and Environmental Compliance and Restoration	29.1
Johnson Space Center (JSC) Total	**5,161.1**
Deep Space Exploration Systems	441.8
Exploration Research and Technology	14.8
LEO and Spaceflight Operations	278.5
Science	265.8
Aeronautics	0.0
Education	0.0
Safety, Security, and Mission Services	357.2
Construction and Environmental Compliance and Restoration	44.1
Kennedy Space Center (KSC) Total	**1,402.2**
Deep Space Exploration Systems	22.3
Exploration Research and Technology	26.1
LEO and Spaceflight Operations	10.3
Science	234.7
Aeronautics	148.9
Education	0.0
Safety, Security, and Mission Services	273.0
Construction and Environmental Compliance and Restoration	14.7
Langley Research Center (LaRC) Total	**730.1**
Deep Space Exploration Systems	1,901.1
Exploration Research and Technology	32.9
LEO and Spaceflight Operations	202.8
Science	195.5
Education	0.0
Safety, Security, and Mission Services	413.1
Construction and Environmental Compliance and Restoration	65.0
Marshall Space Flight Center (MSFC) Total	**2,810.4**

FUNDS DISTRIBUTION BY INSTALLATION

Budget Authority ($ in millions)	FY 2019*
Deep Space Exploration Systems	738.7
Exploration Research and Technology	534.8
LEO and Spaceflight Operations	262.4
Science	1,402.2
Aeronautics	68.4
Education	0.0
Safety, Security, and Mission Services	415.4
Construction and Environmental Compliance and Restoration	94.0
Office of Inspector General	39.3
NASA Headquarters (HQ) and Inspector General (IG) Total	**3,555.3**
Deep Space Exploration Systems	36.9
Exploration Research and Technology	1.9
LEO and Spaceflight Operations	35.3
Science	0.1
Education	0.0
Safety, Security, and Mission Services	51.3
Construction and Environmental Compliance and Restoration	7.1
Stennis Space Center (SSC) Total	**132.6**
	19,892.2

* Totals may not add due to rounding.

NOTE: Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2019 allocations should not be considered final or directly comparable to prior year allocations.

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

NASA's workforce continues to be one of its greatest assets for enabling missions in space and on Earth. The Agency remains committed to applying this asset to benefit society, address contemporary environmental and social issues, lead or participate in emerging technology opportunities, collaborate and strengthen the capabilities of commercial partners, and communicate the challenges and results of Agency programs and activities. The civil service staffing levels proposed in the FY 2019 Budget support NASA's scientists, engineers, researchers, managers, technicians, and business operations workforce. It includes civil service personnel at NASA Centers, Headquarters, and NASA-operated facilities. However, the mix of skills and distribution of workforce across the Agency is necessarily changing.

NASA continues to adjust its workforce distribution and mix of skills to address changing mission priorities, with an emphasis on industry and academic partnerships, transferring work in-house from on- and near-site support contracts, and operating in a leaner fiscal environment. A civil service workforce is critical for conducting mission-essential work in research and technology.

NASA will continue to explore opportunities across the Agency to insource work and find efficiencies in workforce productivity, especially in mission support functional areas. The Agency will apply the valued civil service workforce to priority mission work, adjusting the mix of skills where appropriate. Centers will explore cross-mission retraining opportunities for employees whenever possible, offer targeted buyouts in selected surplus skill areas, and continue to identify, recruit, and retain a multi-generational workforce of employees who possess skills critical to the Agency.

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION BY CENTER

	Actual	Estimate	Request	Notional			
	FY 2017	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**	**FY 2023**
ARC	1,155	1,176	1,166	1,166	1,166	1,166	1,166
AFRC	537	535	531	531	531	531	531
GRC	1,538	1,538	1,534	1,534	1,534	1,534	1,534
GSFC	3,178	3,245	3,240	3,240	3,240	3,240	3,240
JSC	2,989	2,960	2,945	2,945	2,945	2,945	2,945
KSC	1,968	1,954	1,926	1,926	1,926	1,926	1,926
LaRC	1,796	1,805	1,789	1,789	1,789	1,789	1,789
MSFC	2,279	2,326	2,298	2,298	2,298	2,298	2,298
SSC	302	302	295	295	295	295	295
HQ	1,098	1,104	1,084	1,084	1,084	1,084	1,084
NSSC	143	148	146	146	146	146	146
NASA Total*	**16,983**	**17,093**	**16,953**	**16,953**	**16,953**	**16,953**	**16,953**
OIG	192	213	213	213	213	213	213

**Totals may not add due to rounding. All actuals and estimates include direct-funded and reimbursable FTE.*

NOTE: The table may differ from amounts presented in the FY 2019 Budget Appendix to reflect corrections made after the Appendix production.

NOTE: Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2019 allocations should not be considered final or directly comparable to prior year allocations.

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

FY 2019 FTE DISTRIBUTION BY ACCOUNT BY CENTER

	Science	Aeronautics	Exploration Research and Technology	Deep Space Exploration Systems	LEO and Spaceflight Operations	Education	Safety, Security, and Mission Services	Reimbursable / Working Capital Fund**	OIG	NASA-Funded Total	Agency TOTAL
ARC	137	248	121	69	28	-	542	22	-	1,144	1,166
AFRC	99	177	17	8	1	-	213	15	-	516	531
GRC	79	385	167	181	130	-	588	3	-	1,530	1,533
GSFC	1,181	-	133	12	133	-	1,557	224	-	3,016	3,240
JSC	31	-	158	670	1,230	-	857	-	-	2,945	2,945
KSC	-	-	64	542	470	-	849	1	-	1,925	1,926
LaRC	206	520	132	103	5	-	808	15	-	1,774	1,789
MSFC	130	-	127	817	216	-	1,010	-	-	2,300	2,300
SSC	-	-	7	56	40	-	166	27	-	268	295
HQ	12	-	7	-	-	-	1,065	-	-	1,084	1,084
NSSC	-	-	-	-	-	-	-	146	-	-	146
NASA Total*	**1,876**	**1,330**	**932**	**2,456**	**2,252**	**-**	**7,655**	**453**	**-**	**16,500**	**16,953**
OIG									213	213	213

**Totals may not add due to rounding*

***Includes 146 FTE funded by Working Capital Fund; and 307 FTE funded by reimbursable customers*

NOTE: The table may differ from amounts presented in the FY 2019 Budget Appendix to reflect corrections made after the Appendix production.

NOTE: Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2019 allocations should not be considered final or directly comparable to prior year allocations.

WORKING CAPITAL FUND

NASA established the Working Capital Fund (WCF) to satisfy specific recurring needs for goods and services through use of a business-like buyer and seller approach under which NASA's WCF entities provide goods or services pursuant to contracts and agreements with their customers. The overarching aim of WCF is to promote economy, efficiency, and accountability with fully reimbursed rates by focusing on streamlining operations, measuring performance, and improving customer satisfaction.

NASA's WCF is comprised of four entities:

- NASA Shared Services Center (NSSC);
- Solutions for Enterprise-Wide Procurement (SEWP) Government-Wide Acquisition Contract; and
- Information Technology (IT) Infrastructure Integration Program (I3P).
- National Center for Critical Information Processing and Storage (NCCIPS)

WORKING CAPITAL FUNDS BUDGET SUMMARY

Spending Authority from Offsetting Collections ($ millions)	Actual FY 2017	Estimate FY 2018	Request FY 2019
NSSC	73	72	84
SEWP	15	25	30
I3P	325	375	375
NCCIPS	24	31	34
Total Spending Authority	**437**	**503**	**523**
Unobligated Brought Forward, Oct. 1	13	14	17
Recoveries of Prior Yr. Unpaid Obligations	1	4	
Total Budgetary Resources	**451**	**521**	**540**
NSSC	77	74	84
SEWP	14	22	28
I3P	325	377	375
NCCIPS	21	31	34
Total Obligations	**437**	**504**	**521**
Unobligated Balance (end-of-year)*	**14**	**17**	**19**

**Unobligated balance end-of-year is budgetary resources less obligations*

NASA SHARED SERVICES CENTER (NSSC)

NSSC opened in March 2006 to provide centralized administrative processing services and customer contact center operations for support of human resources, procurement, financial management, Agency IT, and Agency business support services. NASA established NSSC, a function under the NASA Headquarters Mission Support Directorate, as a public/private partnership. NSSC has awarded its major business management and IT services contract to CSRA (Computer Sciences Corporation merged with SRA International). Typical expenditures are related to civil service workforce, support contractor, other direct procurements, and Agency training purchases.

NSSC is located on the grounds of SSC and operates in a manner that provides for transparency and accountability of costs and services. NASA has reduced its administrative costs through centralized processing at NSSC. The work performed by NSSC reduces duplicative efforts and increases cost efficiencies.

NSSC's revenue streams include funding from the NASA Centers, mission directorates, and various NASA mission support offices. During FY 2019, NSSC will continue to offer similar services as in FY 2018 with no significant scope changes anticipated.

SOLUTIONS FOR ENTERPRISE-WIDE PROCUREMENT (SEWP)

SEWP refers to operations related to the Government-Wide Acquisition Contract that was established under the authority of section 5112 of the Information Technology Management Reform Act (40 U.S.C. 1412(e)), enacted in 1996, under which NASA is designated by the Office of Management and Budget (OMB) as a Federal Government Executive Agent for SEWP contracts.

SEWP was established as a WCF entity to allow all Federal agencies use of a best value tool to purchase IT product solutions and services. Under this approach, the buying power of Federal Agencies is combined to acquire best value for IT products and services more efficiently. Typical acquisitions include a wide range of advanced technologies such as UNIX-Linux and Windows-based desktops and servers, along with peripherals, network equipment, storage devices, security tools, software, and other IT products and product-based solutions.

SEWP promotes aggressive pricing using online tools to obtain multiple, competitive quotes from vendors. On average for FY 2018, SEWP quotes have a 20-percent savings for any Federal customer using SEWP contracts. In addition, SEWP offers a low surcharge to recover NASA's costs to operate the program with an average 0.39 percent fee as compared to the Government standard of 0.75 percent. SEWP revenue is generated solely from the surcharge fees on all transactions processed. For FY 2018, the Federal Government is projected to save about $13.4 million in service fees, based on the difference between General Services Administration (GSA) and SEWP surcharge fees.

IT INFRASTRUCTURE INTEGRATION PROGRAM (I3P)

WCF operations supporting I3P began in early FY 2012. WCF enables I3P to improve the efficiency and economy in which contract services and management are provided to support NASA's IT strategic initiatives and to increase visibility into NASA's IT budget and expenditures. Under I3P, NASA has consolidated 19 separately managed contracts into 5 centrally managed ones described as follows:

- The Enterprise Applications Service Technologies contract supports Agency Applications Office (AAO) applications hosted by MSFC. The AAO operates and maintains a broad spectrum of NASA's enterprise applications, with an emphasis on fully integrating business process expertise with application and technical knowledge. A small team of civil servants and support contractors sustain operations, implement new applications and capabilities, and provide business readiness support to the stakeholders and end-users.
- The NASA Integrated Communications Services contract provides wide and local area network, telecommunications, video, and data services hosted at MSFC.

- The Web Enterprise Service Technologies contract provides public Web site hosting, Web content management and integration, and search services. GSFC and ARC host these services.
- The Agency Consolidated End-User Services contract provides program management, provisioning, and support of desktops, laptops, cell phones, personal digital assistants, office automation software, and video conferencing. NSSC hosts these services.
- The Networx Telecommunications Circuits contract provides telecommunication services including, tele-conferencing services, core circuit services, mission network services, and regional circuit services hosted at MSFC.

I3P's consolidated contracting approach benefits NASA by providing cost saving opportunities, such as the reduction in administrative burden involved with the business management of contracts and a significant reduction in procurement request transaction volume. Other I3P benefits include the streamlining budgeting, funding, and costing of I3P services; achieving transparency through the provision of detailed customer monthly billings; and providing consolidated, consistent reporting of Agency-wide consumption of I3P-related goods and services.

I3P is unique in that revenue streams and expenditures are limited to contract costs for its five service contracts. Revenue streams include funding from the NASA Centers, NASA Mission Directorates, and various NASA mission support offices. As reflected in the FY 2019 anticipated funding level, the I3P WCF will continue to offer similar services as in FY 2018.

NATIONAL CENTER FOR CRITICAL INFO. PROCESSING AND STORAGE (NCCIPS)

NCCIPS is a federal shared services data center (as defined by the Uptime Institute) designed for sensitive and secure processing and storage. NCCIPS is a 200,000 sq. ft. secure data center facility on a 64 acre campus within the Stennis Space Center. NCCIPS offers federal customers collocation services from a state-of-the-art data center. NCCIPS offers 24x7x365 availability at a Tier III level, with complete redundancy in the electrical distribution system from the national grid to the rack level.

NCCIPS provides the following infrastructure/services:

- Four Layer Security – Buffer Zone/perimeter fencing, armed security at all gates, roving guards, and NCCIPS Guards (Internal NCCIPS Security Systems)
- Two separate National Power Grid feeds to SSC and three separate power feeds available to NCCIPS
- Power infrastructure is fully redundant from National Power Grid down to the racks on the floor
- Expert IT staff with a proven track record of uninterrupted service
- 24x7 facility operations staff monitoring
- Tier III redundant (N + 1) power from two national grids with diesel generator backup
- Robust network infrastructure with multiple, discreet communication paths
- FE-25 clean agent fire suppression

The NASA WCF provides NASA with a mechanism to collect amounts sufficient to finance continuing operations, acquire capital assets, and adjust for prior year results of operations, in addition to normal operating expense recovery at NCCIPS. NCCIPS WCF benefits NASA and its customers by:

- Enabling funds to be collected over time and (once earned) used for new equipment and technology;

- Allowing the NSSC to incorporate a level equipment replacement, maintenance and technology refresh cost into client rates;
- Helping to normalize rates charged to NCCIPS clients from year to year, as the need for facility repairs, infrastructure upgrades, and routine equipment maintenance increases, thus enabling NCCIPS clients to maintain their appropriation funding without incurring potentially large unplanned expenses;
- Facilitating NCCIPS business opportunities for new clients; and
- Reducing the probability of hardware failure within the NCCIPS operational environment.

NCCIPS' revenue streams include funding from the NASA SSC and NSSC Centers and External Federal Agencies such as Department of Homeland Security (DHS), U.S. Navy Department of Defense Supercomputing Resource Center (NDSRC), Government Services Administration (GSA), Department of Transportation Maritime(DOT-MARAD), Department of Transportation OCIO (DOT-OCIO) and Department of Housing and Urban Development (HUD). During FY 2019, NCCIPS will continue to offer similar services as in FY 2018 with no significant scope changes anticipated.

BUDGET BY OBJECT CLASS

FY 2019 Estimated Direct Discretionary Obligations
($ millions)

Code	Object Class	Deep Space Exploration Systems	Exploration Research and Technology	LEO and Spaceflight Operations	Science	Aeronautics	Education	Safety, Security, and Mission Services	Construction & Environmental Compliance & Restoration	Office of Inspector General	NASA Total
11.1	Full-time permanent	327	94	296	249	109	-	869	-	24	1,968
11.3	Other than full-time permanent	2	1	3	3	2	-	17	-	-	28
11.5	Other personnel compensation	2	-	2	1	-	-	29	-	-	34
11.9	*Subtotal Personnel Compensation*	*331*	*95*	*301*	*253*	*111*	-	*915*	-	*24*	*2,030*
12.1	Civilian personnel benefits	107	31	96	79	34	-	278	-	9	634
13	Benefits to former personnel	-	-	-	-	-	-	1	-	-	1
	Total Personnel Compensation & Benefits	**438**	**126**	**397**	**332**	**145**	**-**	**1,194**	**-**	**33**	**2,665**
21	Travel & transport. of persons	15	10	12	24	5	-	22	-	1	89
22	Transportation of things	1	2	1,362	5	-	-	2	-	-	1,372
23.1	Rental payments to GSA	-	-	-	-	-	-	7	-	-	7
23.2	Rental payments to others	-	-	3	8	-	-	22	-	-	33
23.3	Communications, utilities & misc.	15	-	4	4	6	-	59	1	-	89
24	Printing & reproduction	-	-	-	1	-	-	3	-	-	4
25.1	Advisory & assistance services	473	31	77	80	20	-	263	26	-	970
25.2	Other services	49	44	116	93	39	-	245	14	3	603
25.3	Other purchases of goods & services from Government accounts	43	10	23	246	5	-	48	16	1	392
25.4	Operation & maintenance. of facilities	110	5	34	9	21	-	217	74	-	470
25.5	Research & development contracts	3,063	650	2,319	4,196	279	-	175	7	-	10,689
25.6	Medical care	-	-	-	-	-	-	8	-	-	8
25.7	Operation & maintenance of equipment	159	30	212	105	31	-	405	17	1	960
26	Supplies & materials	28	9	17	27	20	-	16	-	-	117
31	Equipment	47	16	15	33	29	-	32	1	-	173
32	Land & structures	55	-	4	1	2	-	16	232	-	310
41	Grants, subsidies, & contributions	63	70	30	731	32	-	16	-	-	942
	Other Object Classes	**4,121**	**877**	**4,228**	**5,563**	**489**	**-**	**1,556**	**388**	**6**	**17,228**
	NASA Total, Direct	**4,559**	**1,003**	**4,625**	**5,895**	**634**	**-**	**2,750**	**388**	**39**	**19,892**

**Totals may not add due to rounding*

NOTE: The table only reflects the FY 2019 request and does not include remaining funding from previous direct or supplemental appropriations.

STATUS OF UNOBLIGATED FUNDS

The table below displays actual and estimated unobligated balances of direct and reimbursable budget authority in each NASA account at the end of each fiscal year. The data is non-comparable, or based solely on an appropriation account's activity or projected activity with no adjustment to the FY 2017 or FY 2018 amounts to make them comparable to the budget structure underlying the FY 2019 request.

UNOBLIGATED FUNDS SUMMARY BY APPROPRIATIONS ACCOUNT

Budget Authority ($ millions)	**Unobligated Balances Sept. 30, 2017**	**Estimated Unobligated Balances Sept. 30, 2018**	**Estimated Unobligated Balances Sept. 30, 2019**
Deep Space Exploration Systems	81	187	293
Exploration Research and Technology	42	42	42
LEO and Spaceflight Operations	91	449	557
Science	298	361	421
Aeronautics	12	12	12
Safety, Security, and Mission Services	451	499	547
Construction and Environmental Compliance and Restoration	147	209	271
Office of Inspector General	39	40	41
Total NASA	**1,161**	**1,799**	**2,184**

**Totals may not add due to rounding*

NOTE: Table does not include estimated unobligated balances for supplemental appropriations.

REIMBURSABLE ESTIMATES

Reimbursable agreements are agreements where the NASA costs associated with the undertaking are borne by the non-NASA partner. NASA undertakes reimbursable agreements when it has equipment, facilities, and services that it can make available to others in a manner that does not interfere with NASA mission requirements. As most reimbursable requests to NASA do not occur until the year of execution, the FY 2018 to FY 2019 estimates are based on an annual survey of Centers' anticipated reimbursable agreements. NASA separately budgets for and executes the four categories of reimbursable agreements listed below. Within the non-EUL amounts, reimbursable agreements are used for a range of activities; for example, use of NASA operated wind tunnel test facilities or rocket test stand facilities by other government agencies and private sector users. NASA also serves as the acquisition agent for NOAA's GOES series of satellites, under a reimbursable agreement between the two agencies. Reimbursable agreements are managed by each individual program offices: Aeronautics, Exploration, Space Operations, Science, Space Technology, and Education at the NASA centers under Safety, Security, Mission Services (SSMS) fund appropriation for reimbursable agreement authorities: Space Act, Economy Act, Commercial Space Launch Act, and Commercial Space Competitiveness Act. Supporting data for Enhanced Use Leasing (EUL) and National Historic Preservation Act (NHPA) is provided in the respective sections below.

REIMBURSABLE ESTIMATES BY APPROPRIATIONS ACCOUNT

($ millions)	Actual	Request	Estimate
	FY 2017	**FY 2018**	**FY 2019**
Safety, Security, and Mission Services (non-EUL)	2,485.1	2,777.6	2,009.5
Aeronautics	*105.3*	*121.5*	*98.9*
Safety, Security, Mission Services	*52.5*	*10.3*	*8.5*
Exploration	*151.7*	*181.0*	*160.1*
Space Operations	*252.1*	*400.3*	*320.0*
Science	*1,922.6*	*1,513.3*	*1,190.7*
Space Technology	*0.9*	*551.2*	*231.3*
Safety, Security, and Mission Services (EUL)	16.7	17.8	19.1
Safety, Security, and Mission Services (NHPA)	13.9	20.2	22.8
Office of Inspector General	1.0	1.5	1.5
Total	**2,516.7**	**2,817.1**	**2,052.9**

ENHANCED USE LEASING

In 2003, Congress authorized NASA to demonstrate leasing authority and collections at two Centers. In 2007 and 2008, Congress amended that authority such that NASA may enter into leasing arrangements at all Centers. The EUL authority originally included a sunset provision (enacted as part of the FY 2009 Omnibus Appropriations Act (P.L. 110-161)) under which NASA's authority would expire on December 26, 2017. The NASA Transition Authorization Act of 2017 amended Section 20145(g) of title 51, United States Code, by striking "10 years after December 26, 2007" and inserting "December 31, 2018", thereby extending the authority through 2018. The EUL authority provides NASA the ability to maintain critical facilities and address deferred maintenance challenges as well as support Centers' revitalization plans. Additionally, NASA's EUL Authority supports important relationships with industry, academia, and non-profit organizations.

After deducting the costs of administering the leases, Centers are then permitted to retain 65 percent of net receipt revenue, and the balance is made available Agency-wide for NASA. These funds are in addition to annual appropriations. To ensure annual oversight and review, the 2010 Consolidated Appropriations Act, P.L. 111-117 contains a provision that requires NASA to submit an estimate of gross receipts and collections and proposed use of all funds collected in the annual budget justification submission to Congress. The table below depicts the estimated FY 2019 EUL expenses and revenues. The amounts identified under Capital Asset Account Expenditures may be adjusted between projects listed based on actual contract award. There are no civil servants funded from EUL income.

SUMMARY OF FY 2019 EUL ACTIVITY

FY2019 EUL Expenses and Revenues ($ Thousands)	ARC	GSFC	JPL(NMO)	KSC	MSFC	SSC	Agency	Total
Base Rent	8,551.8	65.6	99.3	515.0	302.5	84.1	0.0	9,618.3
Institutional Support Income	1,026.1	8.5		15.5		8.3		1,058.4
Additional Reimbursable Demand Services Requested by Lessees (including overhead)	7,868.4			47.5		15.0	500.0	8,430.9
Total Lease Income (EULX52019L)	**17,446.3**	**74.1**	**99.3**	**578.0**	**302.5**	**107.4**	**500.0**	**19,107.6**
Institutional Support Costs	-1,026.1	-8.5		-15.5		-0.3	0.0	-1,050.4
Lease Management and Administration	-851.5				-10.5	-1.4	0.0	-863.4
Tenant Building Maintenance and Repair	-1,064.9				-153.0	-8.0	0.0	-1,225.9
Cost to Fulfill Reimbursable Demand Services (including overhead)	-7,868.4	0.0	0.0	-47.5	0.0	-15.0	-500.0	-8,430.9
Total Cost Associated with Leases	**-10,810.9**	**-8.5**	**0.0**	**-63.0**	**-163.5**	**-24.7**	**-500.0**	**-11,570.6**
Net Revenue from Lease Activity	**6,635.4**	**65.6**	**99.3**	**515.0**	**139.0**	**82.7**	**0.0**	**7,537.0**
Beginning Balance, Capital Asset Account (2018 Ending Balance)	**0.0**	**0.0**	**64.5**	**129.4**	**1.7**	**0.0**	**3,269.1**	**3,464.7**
Net Revenue from Lease Activity Retained at Center (EULX52019E)	**4,313.0**	**42.6**	**64.5**	**334.8**	**90.4**	**53.8**	**2,637.9**	**7,537.0**
Total Available, Capital Assest Account	**4,313.0**	**42.6**	**129.0**	**464.2**	**92.1**	**53.8**	**5,907.0**	**11,001.7**
Planned Maintenance, Various Buildings	-2,107.1	-42.6			-40.0			-2,189.7
Replace Roofs on Varous Buildings	-2,205.9				-50.0			-2,255.9
Misc. Renewable Solar Energy Expansion				-464.2				
Replace Bldg 1 main steam condensate piping								0.0
Upgrade Lighting Systems (Green Project)								0.0
Energy and Sustainability Upgrades, Various Buildings						-53.8		-53.8
Energy and Sustainability Upgrades, Various Buildings (Various Centers)							-4,506.7	-4,506.7
Capital Asset Account Expenditures	**-4,313.0**	**-42.6**	**0.0**	**-464.2**	**-90.0**	**-53.8**	**-4,506.7**	**-9,470.3**
Capital Asset Account Ending Balance	**0.0**	**0.0**	**129.0**	**0.0**	**2.1**	**0.0**	**1,400.3**	**1,531.4**
In Kind Activity	**175.0**	**0.0**	**0.0**	**779.2**	**0.0**	**0.0**	**0.0**	**954.2**

ENHANCED USE LEASING

DEFINITIONS

Base Rent

Revenue collected from the tenant for rent of land or buildings.

Institutional Support Costs

Cost for institutional shared services, such as fire, security, first responder, communications, common grounds, road, and infrastructure maintenance, and routine administrative support and management oversight (e.g., environmental).

Total Rental Income

Total gross proceeds from EUL activities for expenses due to renting NASA property.

In-Kind

Consideration accepted in lieu of rent payment (only applies to selected leases signed prior to January 1, 2009).

Reimbursable Demand Services

Services such as janitorial, communications, and maintenance that solely benefit the tenant and are provided for their convenience. There is no net income received by NASA, as these payments may only cover the costs of NASA and its vendors providing these services.

NATIONAL HISTORIC PRESERVATION ACT

In FY 2014, NASA established a new fund based upon the National Historic Preservation Act (NHPA) of 1966. The Act provides the authority to administer, operate, manage, lease and maintain property, and demolish or remove buildings or space in buildings owned by NASA. It also allows any funds received from leasing the properties, buildings, or space in buildings to be deposited to the credit of a special receipt account and expended for purposes of operating, maintaining, and managing the properties and demolishing or removing the buildings. Agreements or contracts with public or private agencies, corporations, or persons, upon such terms and conditions, are allowed. There are no civil servants funded from the NHPA Fund. The NHPA activities will be maintained under NHPA authority under Section 111. These funds are in addition to annual appropriations.

The table below depicts the estimated amounts of anticipated NHPA expenses and revenues for FY 2019. NASA currently expects total rental income of $19.2 million. Of the total rental income of $19.2 million, $9.5 million represents net revenue from lease activities. The net revenue amount of $9.5 million will be used for historic building maintenance and repairs for historic properties at ARC, as well as for other properties throughout the Agency.

FY2019 NHPA Expenses and Revenues ($ thousands)	**ARC**
Base Rent	15,500.0
Institutional Support Income	3,676.3
Cost to Fuflill Reimbursable Demand Services	3,611.1
Total Rental Income	**22,787.4**
Institutional Support Costs	(9,396.4)
Lease Management and Administration	(283.2)
Reimbursable Demand Services Requested by Leasees	(3,611.1)
Total Cost Associated with Leases	**(13,290.7)**
Net Revenue from Lease Activity	**9,496.7**
Unobligated Proceeds Prior Years (as of 9/30/2018)	
Maintenance for Buildings 2, 10, 15, 16, 17, 19, 20, 25, 26, N200, N227, N234, N238 & N243	(995.6)
Historic Preservation of Building 25, Phase 2 of 2	(2,092.8)
Seismic Retrofit for Building 2	(3,250.0)
Restore Reliability of UPWT Auxiliaries Cooling Water Piping, N227D	(2,366.9)
Capital Asset Account Expenditures	**(8,705.3)**
Capital Asset Account Ending Balance	**791.4**
In Kind Activity	**-**

NATIONAL HISTORIC PRESERVATION ACT

DEFINITIONS

Base Rent

Revenue collected from the tenant for rent of land or buildings.

Institutional Support Costs

Cost for institutional shared services such as fire, security, first responder, communications, common grounds, road, and infrastructure maintenance, and routine administrative support and management oversight (e.g., environmental).

Total Rental Income

Total gross proceeds from NHPA activities for expenses due to renting NASA property.

In-Kind

Consideration accepted in lieu of rent payment.

Reimbursable Demand Services

Services such as janitorial, communications, and maintenance that solely benefit the tenant and are provided for their convenience. There is no net income received by NASA, as these payments may only cover the costs of NASA and its vendors providing these services.

BUDGET FOR MICROGRAVITY SCIENCE

BUDGET FOR INTERNATIONAL SPACE STATION (ISS) RESEARCH

The Human Exploration and Operations Mission Directorate supports research which takes advantage of the unique environment of reduced gravity on the International Space Station (ISS). ISS Research is conducted in two broad categories:

$ in millions	FY 2017 Actual	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Exploration ISS Research	$174	$204	$245	$240	$252	$260	$251
Non- Exploration ISS Research	$204	$143	$148	$141	$145	$131	$125
Total	**$378**	**$347**	**$394**	**$381**	**$397**	**$391**	**$376**
% of Non-Exploration to Total	54%	41%	38%	37%	37%	33%	33%

The amounts included for FY 2017 reflect actuals, FY 2018 through FY 2023 are reflective of the NASA outyear planning.

Exploration ISS Research

Exploration ISS Research supports the Agency's need for improved knowledge about working and living in space to enable future long-duration human exploration missions. The Human Research Program provides research results that reduce risks to crew health and performance from prolonged exposure to reduced gravity, space radiation, and isolation during exploration missions. Research on ISS is mitigating risks to humans in space and on Earth by conducting research in human health countermeasures, space human factors and habitability, behavioral health and performance, and exploration medicine, tools, and technologies. ISS Research investigates the underlying gravity-dependent phenomena in areas vital to the design of future space vehicles and systems: fire prevention, detection, and suppression; boiling and multiphase flow; capillary phenomena; and the response to the space environment of microbes, plants, and higher lifeforms. These applied research investigations will provide the necessary data for the future design of the following technology areas: life support systems, propellant storage, power generation, thermal control, and advanced environmental monitoring and control. Multi-User System Support (MUSS) is responsible for the integration of all ISS payloads including NASA, international partners, and non-NASA users and supports both Exploration and non-Exploration ISS Research. This includes coordinating payload completion schedules, ISS mission schedules, and the space available on the launch vehicles. The applicable MUSS funding is included in the table above.

Non-Exploration ISS Research

NASA allocates at least 15 percent of the funds budgeted for ISS research to ground-based, free-flyer, and ISS life and physical science research that is not directly related to supporting the human space exploration program, in accordance with Section 204 of the NASA Authorization Act of 2005. The purpose is to ensure the effective use of the ISS in its capacity to support space-based basic and applied scientific research with broad national benefits, supporting research that can be advanced significantly through the use of the microgravity environment. This budget supports basic ISS research in fields including, physiological research, fluid physics, combustion science, atomic physics, cell science, materials science, and plant research. This research helps to sustain U.S. scientific expertise and capability in microgravity research and to identify new areas for participation by commercial entities or other government agencies. The Non-Exploration ISS Research line in the previous table also includes the Center for the Advancement of Science in Space (CASIS), the Alpha Magnetic Spectrometer (AMS) and the applicable MUSS funding. CASIS is the organization selected by NASA to manage non-NASA use of the ISS National Laboratory. AMS is a particle physics and astrophysics experiment on ISS which is searching for dark matter, anti-matter, and strange matter.

BUDGET FOR SAFETY OVERSIGHT

The following table provides the safety and mission assurance budget request. This includes the agency-wide safety oversight functions as well as the project specific safety, reliability, maintainability and quality assurance elements embedded within individual projects. NASA does not have a single safety oversight budget line item, but instead amounts are embedded in program, project, and mission support budgets.

BUDGET SUMMARY FOR SAFETY OVERSIGHT

	Actual	Estimate	Request	Notional			
Budget Authority ($ millions)	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Safety and Mission Assurance (AMO)	49.6	49.3	49.5	49.5	49.5	49.5	49.5
Institutional Operational Safety (CMO)	35.6	40.0	39.7	39.7	39.7	39.7	39.7
SMA Technical Authority (CMO)	49.8	51.3	47.9	47.9	47.9	47.9	47.9
Agency-wide Safety Oversight	**135.0**	**140.5**	**137.1**	**137.1**	**137.1**	**137.1**	**137.1**
Program Specific*	**300.0**	**300.0**	**300.0**	**300.0**	**300.0**	**300.0**	**300.0**
NASA Total, Safety	**435.0**	**440.5**	**437.1**	**437.1**	**437.1**	**437.1**	**437.1**

* Estimated values

Agency-Wide Safety Oversight - Agency level programs and activities that support the overarching NASA Safety and Mission Success program.

Safety and Mission Assurance - The Safety and Mission Assurance program administers and refines the pertinent policies, procedural requirements, and technical safety standards. The program participate in forums that provide advice to the Administrator, Mission Directorates, Program Managers and Center Directors who are ultimately accountable for the safety and mission success of all NASA programs, projects, and operations. Specific program responsibility include, among other activities, managing NASA's Orbital Debris program, NASA's Electronic Parts program, and the NASA Safety Center.

Institutional Operational Safety - NASA's institutional operational safety program is driven by OSHA 29 CFR 1960, OSHA Standards, NPR 8715.1A, NASA Occupational Safety and Health Programs, NPR 8715.3D, and NASA's General Safety Program Requirements. The program includes construction safety, mishap prevention program including reporting and investigations, safety training, safety awareness, the voluntary protection program, safety metrics and trend analysis, contractor insight/oversight, support to safety boards and committees, support to emergency preparedness and fire safety program, aviation safety, explosives and propellants safety, nuclear safety requirements, radiation safety protection, confined space entry, fall protection, lifting devices, pressure vessel safety, hazard reporting and abatement systems, cryogenic safety, electrical safety requirements (lock out/tag out), facility systems safety, risk management, institutional safety policy development, visitor and public safety, and institutional safety engineering. The institutional operational safety program requires significant federal state and local coordination.

S&MA Technical Authority and S&MA Support - The S&MA technical authority program includes travel and labor only for all S&MA supervisors, branch chiefs or above and designated deputies. In addition, where the principal job function of a non-supervisory S&MA person consists of rendering authoritative decisions on S&MA requirements matters relating to the design or operation of a program or project, that person's salary is included. These positions often are the lead S&MA manager positions for large programs where the decision making process is nearly a full time demand. This category does not include salary for those whose work only occasionally falls as an authority task. This includes travel funds in direct support of these individuals.

S&MA is mission support, including administrative support, which cannot be directly charged to a program. This budget includes policy development across the programs, range safety, payload safety (ground processing), independent assessments, metrology and calibration (for center), reliability and maintainability policy, center wide S&MA program integration and analysis, business and administrative support to S&MA Directorates, and quality assurance for facilities and ground support hardware.

Program Specific - Project specific S&MA costs are included in individual project budgets. These costs include the technical and management efforts of directing and controlling the safety and mission assurance elements of the project. This incorporates the design, development, review, and verification of practices and procedures and mission success criteria intended to assure that the delivered spacecraft, ground systems, mission operations, and payload(s) meet performance requirements and function for their intended lifetimes.

PHYSICIANS' COMPARABILITY ALLOWANCE

Physicians' Comparability Allowance (PCA) Worksheet

1) Department and component:

National Aeronautics and Space Administration

2) Explain the recruitment and retention problem(s) justifying the need for the PCA pay authority.

(*Please include any staffing data to support your explanation, such as number and duration of unfilled positions and number of accessions and separations per fiscal year.)*

NASA currently has 21 physicians, all located at Johnson Space Center in Houston, Texas. There are a number of recruitment and retention challenges at JSC.

- The Houston area has world-renowned medical facilities. Physician salaries in the Houston area and across the country continue to rise and compensation at JSC must remain competitive in order to attract and retain high quality physicians. Further, since the majority of the physicians are at the GS-15 step 10 level, their compensation is frozen by federal pay statute and has not changed even while private sector pay has continued to increase.
- JSC's clinical resources focus on multiple programs: International Space Station crew (operating 24/7), Commercial Crew Program, Orion Program, support of the active astronaut corps, and the operation of the Lifetime Surveillance of Astronaut Health program (which includes all retired astronauts). Physicians at JSC are also using their expertise to inform human system risks and support Human Research Program efforts.
- Physicians who are board-certified in Aerospace Medicine and who have operational experience are a rare and valuable commodity. There is a shortage of aerospace medicine specialists nationwide; the same physicians are being actively recruited by commercial space companies, other government and military organizations.
- Many of the JSC physicians with aerospace medicine training and experience are also board-certified in other clinical specialties including internal medicine, emergency medicine, and psychiatry. The double board-certified physicians are especially rare and their dual areas of expertise are extraordinarily valuable to NASA. The training period after medical school, including on-the-job training at NASA after hire, is nearly a full decade. Retaining such physicians after they are hired and have completed NASA Flight Surgeon training requirements is critical to the success of the human space flight program. PCA plays a key part in retaining them.

PCA is an important tool in recruiting new physicians as the GS salary offered is consistently lower than salaries in the private sector. In the past year, three surgeons have resigned from JSC to accept positions outside the Federal Government. As a result, JSC is planning to hire 3 to 4 physicians in the next two years in order to meet the Agency's needs. Currently, more than a third of JSC's physicians are retirement eligible and in the next five years 50% will become eligible. JSC is facing a challenge in retaining physicians and having the capability to fill positions that become vacant due to resignations and/or retirements. Being able to offer PCA has become increasingly critical to NASA in competing with the private sector for the most qualified physicians.

PHYSICIANS' COMPARABILITY ALLOWANCE

3-4) Please complete the table below with details of the PCA agreement for the following years:

	PY 2017 (Actual)	CY 2018 (Estimates)	BY* 2019 (Estimates)
3a) Number of Physicians Receiving PCAs	23	24	24
3b) Number of Physicians with One-Year PCA Agreements	23	24	24
3c) Number of Physicians with Multi-Year PCA Agreements			
4a) Average Annual PCA Physician Pay (without PCA payment)	$163,474	$165,811	$165,811**
4b) Average Annual PCA Payment	$21,226	$20,648	$20,648

*BY data will be approved during the BY Budget cycle. Please ensure each column is completed.
**Estimated salary increase in FY 2019 is 0%.

5) Explain the degree to which recruitment and retention problems were alleviated in your agency through the use of PCAs in the prior fiscal year.

(*Please include any staffing data to support your explanation, such as number and duration of unfilled positions and number of accessions and separations per fiscal year.)*

PCA remains a very effective tool for NASA in both recruiting and retaining physicians. It has been used successfully at JSC to recruit and retain highly qualified physicians over the last several years. PCA is used successfully to bridge the widening gap between the compensation that such uniquely qualified physicians can earn in the private sector versus Federal Government service.

JSC had no vacancies in FY16 and was able to avoid physician resignations in part due to the use of PCA to compensate for the difference between federal and non-federal pay. According to the 2017 Medscape Physician Compensation Report, the average physician compensation in the South Central geographical area was $300,000. Emergency physicians, which make up a large portion of JSC's double board certified physicians, earned on average $339,000. In FY17, JSC has had three resignations and is attempting to fill those vacancies with new hires. PCA is a way to lessen the gap with private sector compensation and allow NASA to continue attracting and retaining qualified physicians.

6) Provide any additional information that may be useful in planning PCA staffing levels and amounts in your agency.

With decreasing procurement funds in FY17, which is expected to continue, retaining essential civil service physicians will become increasingly critical to maintaining core competencies and fulfilling mission objectives. For example, the International Space Station (ISS) program has proposed significant cuts to procurement budgets that could shrink the number of contractor flight surgeons available for ISS support. Fluctuations in program funding make it difficult to maintain the critical skills necessary to support current and future programs if there are not enough civil service physicians. Increased competition with new commercial space providers for skilled, experienced physicians is also making it more difficult to retain top talent.

The multi-year Federal pay freeze caused the gap between Federal and private physician salaries to widen and become more evident. The 2013 and 2018 Federal government furlough calls into question the stability of Federal service. Significantly higher physician pay scales under Title 38 in the Veterans Administration and Department of Defense provide a potential incentive for NASA physicians to continue their government service and receive higher pay by transferring to those agencies. All of these factors affect NASA's ability to attract and retain qualified physicians. PCA is a means to lessen the impact of these factors and provide NASA the ability to continue attracting and retaining qualified physicians.

PHYSICIANS' COMPARABILITY ALLOWANCE

Physicians' Comparability Allowance (PCA) Plan

Department and component:

National Aeronautics and Space Administration

Purpose: The purpose of this document is to describe the agency's plan for implementing the Physicians' Comparability Allowance (PCA) program. Per 5 CFR 959.107, OMB must approve this plan prior to the agency entering into any PCA service agreement. Changes to this plan must be reviewed and approved by the Office of Management and Budget (OMB) in accordance with 5 CFR 959.107.

Reporting: In addition to the plan, each year, components utilizing PCA will include their PCA worksheet in the OMB Justification (OMBJ), typically in September. OMB and OPM will use this data for Budget development and congressional reporting.

Plan for Implementing the PCA program:

1a) Identify the categories of physician positions the agency has established are covered by PCA under § 595.103. Please include the basis for each category. If applicable, list and explain the necessity of any additional physician categories designated by your agency (for categories other than I through IV-B). List Any Additional Physician Categories Designated by Your Agency: Pursuant to 5 CFR 595.107, any additional category of physician receiving a PCA, not covered by categories I through IV-B, should be listed and accompanied by an explanation as to why these categories are necessary.

	Category of Physician Position	Covered by Agency (mark "x" if covered)	Basis for Category
Number of Physicians Receiving PCAs by Category (non-add)	Category I Clinical Position	X	Difficulty recruiting and retaining
	Category II Research Position	X	Difficulty recruiting and retaining
	Category III Occupational Health	X	Difficulty recruiting and retaining
	Category IV-A Disability Evaluation	X	Difficulty recruiting and retaining
	Category IV-B Health and Medical Admin.	X	Difficulty recruiting and retaining
Additional category (if applicable)	N/A		
Additional category (if applicable)			

2) Explain the recruitment and retention problem(s) for each category of physician in your agency (this should demonstrate that a current need continues to persist). § 595 of 5CFR Ch. 1 requires that an agency may determine that a significant recruitment and retention problem exists only if all of the following conditions apply:
- Evidence indicates that the agency is unable to recruit and retain physicians for the category;
- The qualification requirements being sought do not exceed the qualifications necessary for successful performance of the work;

PHYSICIANS' COMPARABILITY ALLOWANCE

- The agency has made efforts to recruit and retain candidates in the category; and
- There are not a sufficient number of qualified candidates available if no comparability allowance is paid.

	Category of Physician Position	Recruitment and retention problem
Number of Physicians Receiving PCAs by Category (non-add)	Category I Clinical Position	NASA physicians who receive PCA are all located at Johnson Space Center (JSC) in Houston, Texas. Physician salaries in the Houston area and across the country continue to rise and the General Schedule (GS) salaries that JSC may offer are consistently lower than private sector salaries. According to the 2017 Medscape Physician Compensation Report, the average physician compensation in the South Central geographical area was $300,000. In 2018, the maximum GS salary payable in Houston is $164,200. Significantly higher physician pay scales under Title 38 in the Veterans Administration and Department of Defense provide a potential incentive for NASA physicians to continue their government service and receive higher pay by transferring to those agencies. Further, NASA is now competing with commercial space companies that are attempting to expand their human spaceflight capabilities and need physicians experienced in human spaceflight. JSC's physicians are supporting more critical program activities simultaneously than at any time in the past. This includes support the International Space Station crew (operating 24/7), Commercial Crew, Orion, and Gateway activities, the active astronaut corps, and the operation of the Lifetime Surveillance of Astronaut Health program, which includes all retired astronauts. The recent passage of the TREAT Act means that they will also be providing life-long care for former astronauts. Physicians who are board-certified in Aerospace Medicine and who have operational experience are a rare and valuable commodity. There is a shortage of aerospace medicine specialists nationwide and other government and military organizations are actively recruiting qualified physicians. Many of the JSC physicians with aerospace medicine training and experience are also board-certified in other clinical specialties including internal medicine, emergency medicine, and psychiatry. The double board-certified physicians are an especially rare commodity and their dual areas of expertise are extraordinarily valuable to NASA. The training period after medical school, including on-the-job training at NASA after hire, is nearly a full decade. Retaining such physicians after they are hired and have completed NASA Flight Surgeon training requirements is critical to the success of the human space flight program. All of these factors affect NASA's ability to attract and retain qualified physicians. Without offering PCA, NASA would not be able to recruit and retain qualified physicians.

PHYSICIANS' COMPARABILITY ALLOWANCE

	Category II Research Position	Currently no physician positions in this category
	Category III Occupational Health	Currently no physician positions in this category
	Category IV-A Disability Evaluation	Currently no physician positions in this category
	Category IV-B Health and Medical Admin.	Currently no physician positions in this category
Additional category (if applicable)	N/A	
Additional category (if applicable)		

3) . Explain how the agency determines the amounts to be used for each category of physicians.

	Category of Physician Position	Basis of comparability allowance amount
Number of Physicians Receiving PCAs by Category (non-add)	Category I Clinical Position	The amounts are determined by taking into account current difficulties in recruiting qualified physicians and anticipated retention problems. The amounts paid are the minimum needed to deal with the recruitment and retention problems and are reviewed each year.
	Category II Research Position	Currently no physician positions in this category
	Category III Occupational Health	Currently no physician positions in this category
	Category IV-A Disability Evaluation	Currently no physician positions in this category
	Category IV-B Health and Medical Admin.	Currently no physician positions in this category
Additional category (if applicable)	N/A	
Additional category (if applicable)		

4) Does the agency affirm that the PCA plan is consistent with the provisions of 5 U.S.C. 5948 and the requirements of § 595 of 5CFR Ch. 1?

Yes

BUDGET FOR PUBLIC RELATIONS

The NASA budget for Public Affairs is funded within Safety, Security, and Mission Services under Center Management and Operations and Agency Management and Operations. All the Installations listed below, except for Headquarters, are in the Center Management and Operations account and the Headquarters budget is in the Agency Management and Operations account.

These budgets include dissemination of information to the news media and the general public concerning NASA programs. Content includes support for public affairs/public relations, center newsletters, internal communications, guest operations (including bus transportation), public inquiries, NASA TV, the http://www.nasa.gov portal, and other multimedia support.

NASA PAO BUDGET SUMMARY, BY CENTER

	Actual	Estimate	Request	Notional			
Budget Authority ($ millions)	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**	**FY 2023**
ARC	4.0	3.8	4.1	4.1	4.1	4.1	4.1
AFRC	1.5	1.1	0.9	0.9	0.9	0.9	0.9
GRC	2.9	2.9	3.0	3.0	3.0	3.0	3.0
GSFC	5.6	6.4	6.8	6.8	6.8	6.8	6.8
HQ	13.7	14.1	14.0	14.0	14.0	14.0	14.0
JSC	9.8	9.5	9.7	9.7	9.7	9.7	9.7
KSC	8.3	8.1	8.1	8.1	8.1	8.1	8.1
LaRC	3.0	3.6	3.3	3.3	3.3	3.3	3.3
MSFC	5.8	5.8	5.3	5.3	5.3	5.3	5.3
SSC	1.8	1.0	1.2	1.2	1.2	1.2	1.2
NASA Total	**56.3**	**56.4**	**56.4**	**56.4**	**56.4**	**56.4**	**56.4**

Public Affairs per baseline service level definition as part of the Safety, Security, and Mission Services Budget

CONSULTING SERVICES

NASA uses paid experts and consultants to provide advice and expertise beyond that which is available from its in-house civil service workforce. Management controls ensure that there is ample justification for consulting services before these services are obtained. Much of the Agency's expert and consultant support is for the NASA Advisory Council and the Aerospace Safety Advisory Panel. NASA uses experts and consultants to provide expertise on the selection of experiments for future space missions. The use of these experts and consultants provides the Agency with an independent view that assures the selection of experiments likely to have the greatest scientific merit. Other individuals provide independent views of technical and functional problems in order to provide senior management with the widest possible range of information to support making major decisions. Historically, each Mission Directorate engages a few consultants supporting primarily programmatic and Aerospace Safety Advisory Panel issues.

NASA CONSULTING SERVICES BUDGET SUMMARY

	Actual	Estimate	Request
	FY 2017	**FY 2018**	**FY 2019**
Number of Paid Experts and Consultants	28.0	28.0	28.0
Annual FTE Usage	5.7	5.7	5.7
Salaries	$0.7M	$0.7M	$0.7M
Total Salary and Benefits Costs	$0.8M	$0.8M	$0.8M
Travel Costs	$0.2M	$0.2M	$0.2M
Total Costs	**$1.0M**	**$1.0M**	**$1.0M**

FY 2017 are actual obligations. FY 2018 and FY 2019 are estimated Budget Authority

A broader definition of consulting services could include the total object class "Advisory and Assistance Services" as shown in the Supporting Data Budget by Object Class section of this volume. "Advisory and Assistance Services" include 1) Management and Professional Support Services, 2) Studies, Analysis, and Evaluations, and 3) Engineering and Technical Services.

	Actual	Estimate	Request
(Cost in $ millions)	**FY 2017**	**FY 2018**	**FY 2019**
Quality Control, Testing & Inspection Services	33.9	33.9	33.9
Management and Professional Support Services	776.3	776.3	776.3
Studies, Analysis, & Evaluations	91.8	91.8	91.8
Engineering and Technical Services	6.9	6.9	6.9
IT Services	61.1	61.1	61.1
Total Costs, Advisory & Assistance Ser.	970.0	970.0	970.0

NOTE: The table may differ from amounts presented in the FY 2019 Budget Appendix to reflect corrections made after the Appendix production.

CONSULTING SERVICES

DEFINITIONS

Consultant - A person who can provide valuable and pertinent advice generally drawn from a high degree of broad administrative, professional, or technical knowledge or experience. When an agency requires public advisory participation, a consultant also may be a person who is affected by a particular program and can provide useful views from personal experience.

Expert - A person who is specially qualified by education and experience to perform difficult and challenging tasks in a particular field beyond the usual range of achievement of competent persons in that field. An expert is regarded by other persons in the field as an authority or practitioner of unusual competence and skill in a professional, scientific, technical, or other activity.

These definitions are located under 5 CFR 304.102. The appointments are made under 5 U.S.C. 3109, and the use of this authority is reported to Office of Personnel Management (OPM) annually.

E-GOV INITIATIVES AND BENEFITS

E-GOVERNMENT FUNDING CONTRIBUTIONS AND SERVICE FEES BY INITIATIVE

NASA is providing funding contributions in FY 2019 for each of the following E-Government initiatives:

Initiative	2019 Contributions (Includes In-Kind)	2019 Service Fees*
E-Rulemaking	0	10,000
Grants.gov	146,187	0
E-Training	0	1,583,625
Recruitment One-Stop	0	129,375
Enterprise HR Integration	0	357,500
E-Payroll	0	3,950,075
E-Travel	0	89,520
Integrated Award Environment (IAE)	0	874,354
Financial Management LoB	124,236	0
Human Resources Management LoB	68,478	500,000
Geospatial LoB	225,000	0
Budget Formulation and Execution LoB**	107000	0
Federal PKI Bridge		121,283
NASA Total	**670,901**	**7,615,732**

**Service fees are estimates as provided by the E-Government initiative managing partners*

***Final FY 2019 commitments have yet to be finalized by Managing Partners (OMB MAX)*

After submission of the budget, NASA will post FY 2019 Exhibit 300 IT business cases on the IT Dashboard, located at https://www.itdashboard.gov.

E-GOV INITIATIVES AND BENEFITS

The E-Government initiatives serve citizens, businesses, and federal employees by delivering high quality services more efficiently at a lower price. Instead of expensive “stove-piped” operations, agencies work together to develop common solutions that achieve mission requirements at reduced cost, thereby making resources available for higher priority needs. Benefits realized through the use of these initiatives for NASA in FY 2019 are described in the following.

eRulemaking (Managing Partner EPA) FY 2019 Benefits

NASA’s benefits from the eRulemaking initiative are largely focused on providing the public benefits by providing one-stop access to the Agency’s information on rulemakings and non-rulemaking activities via the Regulations.gov Web site.

NASA uses the Federal Docket Management System (FDMS) to post its rulemakings in order for the public to gain access to review and comment on these rulemakings. NASA relies on Regulations.gov to retrieve public comments on its rulemakings. NASA’s use of the FDMS and Regulations.gov substantially improves the transparency of its rulemaking actions as this use increases public participation in the regulatory process. Direct budget cost savings and cost avoidance result from NASA’s transition to FDMS and Regulations.gov, enabling the Agency to discontinue efforts to develop, deploy, and operate specific individual online docket and public comment systems. Over a five-year period, NASA is estimated to save over $700,000 over alternative options that would provide similar services.

Grants.gov (Managing Partner HHS) FY 2019 Benefits

The Grants.gov initiative benefits NASA and its grant programs by providing a single location with broader exposure to publish grant (funding) opportunities and application packages, making the process easier for applicants to apply to multiple agencies. All 26 major Federal grant making agencies posted 100 percent of their synopses for discretionary funding opportunity announcements on Grants.gov.

In addition, Grants.gov provides a single site for the grantee community to apply for grants using a standard set of forms, processes, and systems giving greater access and ability to apply for Federal funding. Through the use of Grants.gov, NASA is able to reduce operating costs associated with online posting and application of grants. Additionally, the Agency is able to improve operational effectiveness through the use of Grants.gov by increasing data accuracy and reducing processing cycle times.

e-Training (Managing Partner OPM) FY 2019 Benefits

The e-Training initiative provides access to premier electronic training systems and tools that support the training and development of the Federal workforce. The initiative supports agency missions through efficient one-stop access to e-Training products and services. The availability of an electronic training environment enhances the ability of the Federal government and NASA to attract, retain, manage, and develop highly skilled professionals needed for a flexible and high-performing government workforce.

The e-Training initiative benefits NASA by reducing redundancies and achieving economies of scale in the purchase and development of e-learning content and in the purchase of learning technology infrastructure. The System for Administration, Training, and Educational Resources at NASA (SATERN) is a web-based talent management tool that serves as NASA’s training system of record. This centralized approach allows NASA to reduce and leverage training costs by eliminating unique systems, standardizing training processes, and valid data.

Through SATERN, employees can view required training, launch online content, view training history, and self-register for approved courses and conferences. In addition, the system allows NASA officials to identify groups and individuals who have not met basic training requirements and ensure accountability for mission critical and federally mandated training and development. SATERN also offers employees access to career planning tools, individual development plans, and competency management assistance. Currently, SATERN offers learners access to more than 2,500 online courses and 18,000 online books and training videos. SATERN is available at all times and can be accessed from work or at home.

Recruitment One-Stop (Managing Partner OPM) FY 2019 Benefits

USAJOBS simplifies the Federal Job Search Process for Job Seekers and Agencies. The USAJOBS.gov Web site provides a place where citizens can search for employment opportunities throughout the Federal Government. USAJOBS is a fully operational, state of the art recruitment system that simplifies the Federal job search process for job seekers and agencies. Through USAJOBS.gov users have access to:

- A centralized repository for all competitive service
- Job vacancies;
- A resume repository used by agencies to identify critical skills;
- A standardized online recruitment tool and services;
- A standard application Process; and
- Intuitive job searches including e-mail notifications for jobs of interest.

Integration with Recruitment One-Stop allows NASA to better attract individuals who can accomplish the Agency's mission. The USAJOBS interface allows job seekers to view and apply for all NASA employment opportunities, as well as those from other federal agencies.

NASA adopted the USAJOBS resume as the basic application document for all NASA positions, except for astronaut positions (in 2005). To date NASA has not identified any specific savings, either in terms of budgeted savings or cost avoidance. Although the Agency believes that implementation of Recruitment One-Stop has resulted in significant intangible benefits in terms of providing better vacancy information to applicants, it has not resulted in any specific cost savings to NASA. However, the numerous intangible benefits Recruitment One-Stop provides to NASA and other agencies include:

- Decreasing hiring time for managers;
- Providing an integrated solution to agency applicant assessment systems;
- Providing a cost effective marketing and recruitment tool;
- Realizing cost savings over commercial job posting boards;
- Reducing the delay associated with filling critical agency vacancies; and
- Enhancing competition with the private sector for the best and brightest talent for Federal service.

Enterprise HR Integration (Managing Partner OPM) FY 2019 Benefits

The Enterprise HR Integration (EHRI) Program supports the strategic management of human capital by providing agency customers with access to timely and accurate federal workforce data. In support of this objective, EHRI has the following goals: 1) Streamline and automate the exchange of federal employee human resources (HR) information Government wide; 2) Provide comprehensive knowledge management and workforce analysis, forecasting, and reporting across the Executive Branch; 3) Maximize cost savings captured through automation; and 4) Enhance retirement processing throughout the Executive Branch.

E-GOV INITIATIVES AND BENEFITS

A key initiative of EHRI is the electronic Official Personnel Folder (eOPF), a web-based application capable of storing, processing, and displaying the OPFs of all current, separated, and retired Federal Employees. When fully implemented, the eOPF will cover the entire Executive Branch as well as other Federal and Local Governments with a total user population of more than 1.9 million. The system will replace the existing manual process by automating the Federal Government's HR processes and thereby creating a streamlined Federal HR system for all Federal Employees. The initiative is achieving cost savings that are recognized on a per-folder basis. The total cost avoidance per folder is estimated at $55.56.

Specific EHRI/eOPF benefits to NASA include improved convenience in searching, better security and safety to electronic files, more economical, streamlined business processes, and the ability to have a central repository of OPF records for the Agency. During FY 2010, NASA also deployed the eOPF capability of electronic transfer of eOPFs between agencies. Specific NASA employee benefits include secure online access to OPFs, automatic notification when documents are added, exchange of retirement and HR data across agencies and systems, and the elimination of duplicate and repetitive personnel data in personnel folders. NASA completed its implementation to eOPF in March 2008, and transitioned personnel actions processing to the NASA Shared Service Center.

E-Payroll FY 2019 Benefits

The E-Payroll Initiative standardizes and consolidates government-wide federal civilian payroll services and processes by simplifying and standardizing human resources (HR)/payroll policies and procedures and better integrating payroll, HR, and finance functions. Prior to beginning the initiative, 26 federal agencies provided payroll services. Four providers were selected to furnish payroll services for the Executive branch. Since 2004, the Department of Interior (DOI) has served as NASA's payroll provider, using their system, the Federal Personnel and Payroll System (FPPS), to process NASA's HR and Payroll transactions and supply all key delivery aspects of its payroll operation functions. The E-Payroll initiative benefits NASA by permitting the Agency to focus on its mission related activities, rather than on administrative payroll functions. Payroll processing costs are reduced through economies of scale and avoiding the cost of duplicative capital system modernization activities. The initiative also promotes standardization of business processes and practices and unified service delivery.

E-Travel (Managing Partner GSA) FY 2019 Benefits

NASA completed migration of its travel services to ETS2 - Concur Government Edition (CGE) (formerly HP Enterprise Services (FedTraveler)). Completing this migration after implementation the summer of 2014 has allowed NASA to provide more efficient and effective travel management services. ETS2 is a streamlined, adaptable world-class travel management service that continually applies commercial best practices to realize travel efficiencies and deliver a transparent, accountable, and sustainable service that yields exceptional customer satisfaction.

ETS2 builds on the success of the first generation ETS, and will continue to take advantage of advances to help the government further consolidate online travel booking services and expense management platforms, driving additional cost savings and efficiencies while delivering a transparent service for improved accountability and reduced waste. ETS2 serves as the gateway to optimize the government's scale and full market leverage to lower travel costs. ETS has served as the backbone of GSA's managed travel programs, providing access to air, car and lodging, as well as the foundation for implementing a shared service for civilian agency travel management.

ETS2's new benefits and features include:

- Improved usability and optimized online travel planning;
- Increased navigation and ease-of-use, enabling informed cost and sustainability decisions at point-of-sale; and
- Strengthened operational environment, improving management by adopting commercial best practices in software development, data transparency and improved security controls.

ETS2 will enable the government to further consolidate travel services, platforms, and channels, improve the leverage of government travel spending, increase transparency for improved accountability, and reduce waste. This directly aligns and supports the recent Office of Management and Budget Memo M-12-12 regarding *Promoting Efficient Spending to Support Agency Operations* with respect to travel.

Integrated Award Environment (Managing Partner GSA) FY 2019 Benefits

The Integrated Award Environment (IAE) initiative is designed to streamline the process of reporting on subcontracting plans and provide agencies with access to analytical data on subcontracting performance. Use of the IAE common services allows agencies to focus on agency-specific needs such as strategy, operations, and management while leveraging shared services for common functions. Furthermore, use of a government-wide business focused service environment reduces funding and resources for technical services and support for acquisition systems originally housed by individual agencies.

IAE facilitates and supports cost-effective acquisition of goods and services by agencies. The IAE initiative provides common acquisition functions and shared services that benefit all agencies, such as the maintenance of information about business-partner organizations (e.g., banking, certifications, business types, capabilities, performance). IAE provides benefits to the government and business-partner organizations by improving cross-agency coordination that helps to improve the government's buying power, while providing business partners maximum visibility and transparency into the process. IAE provides various services, tools, and capabilities that can be leveraged by the acquisition community including buyers, sellers, and the public to conduct business across the federal government space.

Government buyers can:

- Search for commercial and government sources
- Post synopses and solicitations
- Securely post sensitive solicitation documents
- Access reports on vendors' performance
- Retrieve vendor data validated by SBA and Internal Revenue Service (IRS)
- Identify excluded parties
- Report contract awards

Business suppliers can:

- Search business opportunities by product, service, agency, or location
- Receive e-mail notification of solicitations based on specific criteria
- Register to do business with the federal government
- Enter representations and certifications one time
- Revalidate registration data annually
- Report subcontracting accomplishments

Citizens can:

- Retrieve data on contract awards
- Track federal spending
- Search to find registered businesses
- Monitor business opportunities

Through adoption of the tools and services provided by IAE, NASA improves its ability to make informed and efficient purchasing decisions and allows it to replace manual processes. If NASA did not use IAE systems, the Agency would need to build and maintain separate systems to record vendor and contract information, and to post procurement opportunities. Agency purchasing officials would not have access to databases of important information from other agencies on vendor performance and could not use systems to replace paper-based and labor-intensive work efforts.

Integrated Award and Environment – Loans & Grants FY 2019 Benefits

All agencies participating in the posting and/or awarding of Contracts and Grants & Loans are required by the Federal Funding Accountability and Transparency Act (FFATA) of 2006 and the Digital Accountability and Transparency Act of 2014 (DATA Act) reporting requirements to disclose award information on a publicly accessible Web site. FFATA requires OMB to lead the development of a single, searchable Web site through which the public can readily access information about grants and contracts provided by Federal government agencies[1].

Based on the recommendations of the Transparency Act Taskforce, the Web site leverages functionality provided by the IAE initiative to provide Data Universal Numbering System (DUNS) numbers as the unique identifier. An existing IAE Dun and Bradstreet (D&B) transaction-based contract for the contract community was expanded to provide government-wide D&B services for the Grants & Loans community. These services include parent linkage, help desk support, world database lookup, business validation and linkage monitoring, matching services, as well as the use of DUNS numbers. The enterprise D&B contract provides substantial savings to the participating agencies over their previous agency transaction-based D&B contracts.

[1] More information on the development of this Web site can be found at: https://www.usaspending.gov/Pages/Default.aspx

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E-GOV INITIATIVES AND BENEFITS

On December 14, 2007, OMB launched www.USASpending.gov to meet the Federal Funding Accountability and Transparency Act (FFATA) statutory requirements, ahead of schedule. Since that launch, OMB has and will continue to work with agencies to improve the quality, timeliness, and accuracy of their data submissions and has released a series of enhancements to the site. USASpending.gov complements other Web sites providing the public Federal program performance information (e.g., USA.gov, Results.gov and ExpectMore.gov).

USASpending.gov provides:

- The name of the entity receiving the award;
- The amount of the award;
- Information on the award including transaction type, funding agency, etc.;
- The location of the entity receiving the award; and
- A unique identifier of the entity receiving the award.

Cross-government cooperation with OMB's Integrated Acquisition Environment initiative allows agencies and contributing bureaus to meet the requirements of the FFATA by assigning a unique identifier, determining corporate hierarchy, and validating and cleaning up incorrect or incomplete data.

The FY 2019 funding requirements as it relates to the IAE – Loans and Grants funding line supports the FFATA and DATA Act for the relationship with D&B and DUNS support services. In addition to provision of DUNS numbers, D&B is now providing business and linkage data seamlessly, and the business arrangement supports the quality of data by real-time updates. NASA and other agencies will leverage the linkages to corporate organizational rollups based on parental and subsidiary relationships.

Federal PKI Bridge - FY 2019 Benefits

The Federal Public Key Infrastructure (FPKI) is the primary, secure mechanism that allows for electronic business transactions across government and between government and industry. It is the backbone and trust anchor for HSPD-12 and PIV Cards and is critical to enabling cyber security via identity management. The FPKI enables secur

e physical and logical access through the use of strong credentials such as the PIV card, and allows federal documents to be digitally signed, sent, encrypted, and archived in digital media without fear that they will be compromised, spoofed, or altered. A number of core government-wide documents mandate use of the FPKI.

The FPKI Policy Authority (managed by GSA) is the CIO Council PKI action agent responsible for the governance of the FPKI Ecosystem.

LINES OF BUSINESS

Financial Management LoB (Managing Partners DOE and DOL) FY 2019 Benefits

Treasury's Office of Financial Innovation and Transformation (FIT) served as Managing Partner and the Program Management Office (PMO) for the FMLoB. In accordance with OMB's guidance on shared services (the Federal IT Shared Services Strategy), the Treasury's FIT will lead efforts to transform Federal financial management, reduce costs, increase transparency, and improve delivery of agencies' missions by operating at scale, relying on common standards, shared services, and using state-of-the-art technology. Under the guidance of the CFOC and COFAR, partner agencies will work with the FMLOB's support to standardize core financial business processes (including financial assistance) and data elements across the Federal Government to provide: (1) reliable and accessible financial data to the public; (2) adequate training and development resources to agency workforces; and (3) strong oversight of Federal programs using tools such as the Single Audit. The FMLoB will also play a role in implementing OMB's Memorandum M-13-08, *Improving Financial Systems Through Shared Services*. NASA benefits from the FM LOB because it provides a forum in which federal agencies can share information and weigh pros and cons of various initiatives (for example, shared services).

Human Resources Management LoB (Managing Partner OPM) FY 2019 Benefits

The HR LoB vision is to create government-wide, modern, cost-effective, standardized, and interoperable HR solutions to provide common core functionality to support the strategic management of Human Resources through the establishment of Shared Service Centers (SSCs). Driven from a business perspective, the solutions will address distinct business improvements enhancing the government's performance of HR and payroll services in support of agency missions delivering services to citizens. The HR LoB concept of operations calls for agencies to receive core services from an HR LoB provider. These core services are defined as personnel action processing, compensation management (payroll) and benefits management. Leveraging shared services solutions will allow the HR LoB to significantly improve HR and payroll service delivery, save taxpayer dollars, and reduce administrative burdens.

NASA works in partnership with one of the approved service providers, the Department of Interior's Business Center (IBC). Through this partnership, NASA shares and receives "best-in-class" HR solutions. The Business Center (IBC) delivers NASA-developed solutions to their customer agencies, enabling improved efficiencies and system integrations at a fraction of the cost and delivery time than similar solutions could have been produced by the Interior Business Center. NASA achieves the benefits of "best-in-class" HR solutions through implementation and integration of Interior Business Center (IBC) and NASA-developed HR solutions. NASA's participation in HR LoB provides the Agency opportunities to implement modern HR solutions and benefit from best practices government-wide strategic HR management. NASA participates in the ongoing development of a 10 year Federal Human Resources Strategic Plan with the HRLOB managing partner (OPM) and member agencies.

Geospatial LoB (Managing Partner DOL) FY 2019 Benefits

The Geospatial LoB will better serve the agencies' missions and the Nation's interests developing a more strategic, coordinated, and leveraged approach to producing, maintaining, and using geospatial data and services across the Federal government. Specific goals of the Geospatial LoB include establishing a collaborative governance mechanism, coordinating a government-wide planning and investment strategy, and optimizing and standardizing geospatial data and services.

E-GOV INITIATIVES AND BENEFITS

Contributing agencies and bureaus will receive value from the development of the LoB primarily through improved business performance and cost savings. Enhanced governance processes, improved business planning and investment strategies, and optimization and standardization of geospatial business data and services will produce the following results:

- Collaborative management of geospatial investments will be made more adaptable, proactive and inclusive;
- Enterprise business needs and agency core mission requirements will be identified, planned, budgeted, and exploited in a geospatial context;
- Long-term costs of geo-information delivery and access will be reduced while minimizing duplicative development efforts;
- Effective, yet less costly commercial off the shelf systems and contractual business support operations will replace legacy geospatial applications; and
- Business processes will be optimized and knowledge management capabilities will exist for locating geospatial data and obtaining services.

As a science agency, the work of NASA's science and mission professionals is inherently different from duties and functions performed by operational agencies. These differences lead NASA to organize and manage data to best facilitate science activities rather than a central focus of data dissemination. Scientific inquiry often leads scientist to use different schemas for analyzing data and information produced from remote sensing data (e.g. a common grid or projection). NASA will continue to apply the elements of Federal Geographic Data Committee standards where these are appropriate. In FY 2008, NASA signed an MOU with the Department of Labor to continue its active participation in the Geospatial LOB.

Budget Formulation & Execution LOB (Managing Partner Education) FY 2019 Benefits

The Budget Formulation and Execution LoB (BFELoB) provides significant benefits to NASA and other partner agencies by encouraging best practices crossing all aspects of Federal budgeting – from budget formulation and execution to performance to human capital needs. To benefit all agencies, BFELoB continues to support the idea of shared service budget systems. As NASA currently has its own budgeting tools, the Agency has not chosen to move to a new budget system; however, a shared service budget system is an option moving forward.

BFELoB's "MAX Federal Community," a secure government-only collaborative Web site, provides significant benefits for collaboration across and within agencies, as well as knowledge management. The Community site is commonly used for sharing information, collaboratively drafting documents (including the direct-editing of documents posted on the site).

COMPARABILITY ADJUSTMENT TABLES

FY 2017 Budget Structure Crosswalk to FY 2019 Budget Structure

Budget Authority ($ millions)

NASA TOTAL	**$19,653.3**	**$19,653.3**
Deep Space Exploration Systems	**$4,324.0**	**$4,184.0**
Exploration Systems Development	**$3,929.0**	**$3,929.0**
Orion Program	$1,330.0	$1,330.0
Space Launch System	$2,127.1	$2,127.1
Exploration Ground Systems	$471.9	$471.9
Advanced Exploration Systems		**$97.8**
Adv Cislunar and Surface Capabilities		$0.0
Exploration Advanced Systems Program		$97.8
Exploration Advanced Systems		*$97.8*
HQ Integration Support		$2.8
AES Habitation Capabilities		$95.0
Exploration Research and Development	**$395.0**	**$157.2**
Human Research Program	$140.0	
Advanced Exploration Systems	$255.0	$157.2
Advanced Exploration Systems	*$255.0*	*$157.2*
HQ Integration Support	$2.8	
AES Habitation Capabilities	$95.0	
Exploration Research and Technology	**$686.5**	**$826.5**
Space Technology	**$686.5**	**$826.5**
Human Research Program		$140.0
SBIR and STTR	$199.0	$199.0
Agency Technology and Innovation	$31.9	
Space Technology Research & Development	$455.6	
Early Stage Innovation and Partnerships		$89.7
Technology Maturation		$135.0
Technology Demonstration		$262.8
LEO and Spaceflight Operations	**$4,942.5**	**$4,942.5**
Science	**$5,762.2**	**$5,762.2**
Earth Science	**$1,907.7**	**$1,907.7**
Earth Science Research	$462.0	$462.0
Earth Systematic Missions	$929.7	$929.7
Surface Water and Ocean Topography	*$61.7*	*$61.7*
Sentinel-6		*$54.7*
Landsat 9		*$198.7*
Ice, Cloud, and land Elevation Satellite (ICESat-II)	*$86.5*	*$86.5*
GRACE FO	*$33.7*	*$33.7*
NASA-ISRO SAR	*$101.4*	*$101.4*
Other Missions and Data Analysis	*$646.4*	*$393.1*
Landsat 9	$198.7	$198.7
Sentinel-6	$54.7	$54.7

FY 2017 Budget Structure Crosswalk to FY 2019 Budget Structure

Budget Authority ($ millions)

Earth System Science Pathfinder	$208.8	$208.8
Earth Science Multi-Mission Operations	$204.9	$204.9
Earth Science Technology	$62.9	$62.9
Applied Sciences	$39.4	$39.4
Planetary Science	**$1,827.5**	**$1,827.5**
Planetary Science Research	$290.1	$230.1
Planetary Science Research and Analysis	*$178.1*	*$178.1*
Directorate Management	*$4.1*	
Robotics Alliance	$4.1	
Near Earth Object Observations	*$60.0*	
Near Earth Object Observations	$60.0	
Other Missions and Data Analysis	*$47.9*	*$52.0*
Robotics Alliance		$4.1
Planetary Defense		$60.0
Other Missions and Data Analysis		*$60.0*
Near Earth Object Observations		$60.0
Lunar Discovery and Exploration		$19.0
Other Missions and Data Analysis		*$19.0*
Lunar Reconnaissance Orbiter (LRO)		$19.0
Discovery	$213.6	$194.6
Psyche		*$47.3*
Lucy		*$54.5*
InSight	*$32.3*	*$32.3*
Other Missions and Data Analysis	*$181.3*	*$60.5*
Lunar Reconnaissance Orbiter (LRO)	$19.0	
Lucy	$54.5	
Psyche	$47.3	
New Frontiers	$134.0	$134.0
Origins Spectral Interpretation Resource	*$39.5*	
Origins Spectral Interpretation Resource	$39.5	
Other Missions and Data Analysis	*$94.5*	*$134.0*
Origins Spectral Interpretation Resource		$39.5
Mars Exploration	$647.0	$647.0
Outer Planets and Ocean Worlds	$359.5	$359.5
Jupiter Europa		*$275.0*
Other Missions and Data Analysis	*$359.5*	*$84.5*
Jupiter Europa	$275.0	
Technology	$183.3	$183.3

COMPARABILITY ADJUSTMENT TABLES

FY 2017 Budget Structure Crosswalk to FY 2019 Budget Structure

Budget Authority ($ millions)

Astrophysics	**$782.9**	**$1,352.3**
Astrophysics Research	$190.1	$190.1
Cosmic Origins	$210.0	$779.4
James Webb Space Telescope		*$569.4*
Hubble Space Telescope (HST)	*$97.3*	*$97.3*
Stratospheric Observatory for Infrared Astronomy (SOFIA)	*$85.2*	*$85.2*
Other Missions and Data Analysis	*$27.5*	*$27.5*
Physics of the Cosmos	$106.2	$106.2
Exoplanet Exploration	$152.6	$152.6
Astrophysics Explorer	$124.1	$124.1
James Webb Space Telescope	**$569.4**	
James Webb Space Telescope	$569.4	
James Webb Space Telescope	*$569.4*	
James Webb Space Telescope	$569.4	
Heliophysics	**$674.7**	**$674.7**
Heliophysics Research	$180.8	$180.8
Living with a Star	$368.4	$368.4
Solar Terrestrial Probes	$38.8	$38.8
Heliophysics Explorer Program	$86.7	$86.7
ICON	*$39.4*	
Ionospheric Connection Explorer	$39.4	
Other Missions and Data Analysis	*$47.3*	*$86.7*
Ionospheric Connection Explorer		$39.4
Aeronautics	**$656.0**	**$656.0**
Aeronautics	**$656.0**	**$656.0**
Airspace Operations and Safety Program	$140.6	$140.6
Advanced Air Vehicles Program	$274.6	$274.6
Integrated Aviation Systems Program	$125.0	$125.0
Low Boom Flight Demonstrator		*$18.5*
Low-Boom Flight Demonstrator		$18.5
Integrated Aviation Systems Program	*$106.4*	*$106.4*
Low-Boom Flight Demonstrator	$18.5	$18.5
Transformative Aero Concepts Program	$115.8	$115.8
Education	**$100.0**	**$100.0**

COMPARABILITY ADJUSTMENT TABLES

FY 2017 Budget Structure Crosswalk to FY 2019 Budget Structure

Budget Authority ($ millions)

Safety, Security, and Mission Services	$2,768.6	$2,768.6
Center Management and Operations	**$1,986.5**	**$1,986.5**
Agency Management and Operations	**$782.1**	**$782.1**
Agency Management	$359.2	$359.2
Safety and Mission Success	$176.3	$176.3
Agency IT Services (AITS)	$219.8	$219.8
IT Management	*$15.9*	*$15.9*
Applications	*$56.0*	
Science & Engineering Apps	$6.0	
Business Management Apps	$50.0	
Enterprise IT	*$147.9*	*$203.9*
Information Management		$6.0
Agency Applications		$50.0
Strategic Capabilities Asset Program	$26.8	$26.8
Construction & Envrmtl Compl Restoration	$375.6	$375.6
Inspector General	$37.9	$37.9
NASA TOTAL	**$19,653.3**	**$19,653.3**

NOTE: Chart represents changes in budget structure and does not reflect funding changes.

COMPARABILITY ADJUSTMENT TABLES

FY 2018 Budget Structure Crosswalk to FY 2019 Budget Structure

Budget Authority ($ millions)

NASA TOTAL	**$19,092.2**	**$19,092.2**
Deep Space Exploration Systems	**$3,934.1**	**$3,794.1**
Exploration Systems Development	**$3,584.1**	**$3,584.1**
Advanced Exploration Systems		**$130.9**
Exploration Advanced Systems Program		$130.9
Exploration Advanced Systems		*$130.9*
HQ Integration Support		*$19.0*
AES Habitation Capabilities		*$111.9*
Exploration Research and Development	**$350.0**	**$79.1**
Human Research Program	$140.0	
Human Research Program	*$140.0*	
Advanced Exploration Systems	$210.0	$79.1
Advanced Exploration Systems	*$210.0*	*$79.1*
HQ Integration Support	*$19.0*	
AES Habitation Capabilities	*$111.9*	
Exploration Research and Technology	**$678.6**	**$818.6**
Space Technology	**$678.6**	**$818.6**
SBIR and STTR	$180.0	$180.0
Agency Technology and Innovation	$31.9	
Space Technology Research & Development	$466.7	
Early Stage Innovation and Partnerships		$100.2
Technology Maturation		$148.0
Technology Demonstration		$250.4
Human Research Program		$140.0
LEO and Spaceflight Operations	**$4,740.8**	**$4,740.8**
Science	**$5,711.8**	**$5,711.8**
Earth Science	**$1,754.1**	**$1,754.1**
Planetary Science	**$1,929.5**	**$1,929.5**
Planetary Science Research	$291.5	$241.5
Near Earth Object Observations	*$50.0*	
Planetary Defense		$50.0
Other Missions and Data Analysis		
Near Earth Object Observations		*$50.0*
Lunar Discovery and Exploration		$20.0
Other Missions and Data Analysis		
Lunar Reconnaissance Orbiter (LRO)		*$20.0*
Discovery	$306.1	$286.1
Other Missions and Data Analysis	*$70.3*	*$50.3*
Lunar Reconnaissance Orbiter (LRO)	*$20.0*	

COMPARABILITY ADJUSTMENT TABLES

FY 2018 Budget Structure Crosswalk to FY 2019 Budget Structure

Budget Authority ($ millions)

New Frontiers	$82.1	$82.1
Mars Exploration	$584.7	$584.7
Outer Planets and Ocean Worlds	$457.9	$457.9
Technology	$207.2	$207.2
Astrophysics	**$816.7**	**$1,350.4**
Astrophysics Research	$204.4	$204.4
Cosmic Origins	$191.6	$725.3
James Webb Space Telescope		*$533.7*
Physics of the Cosmos	$99.9	$99.9
Exoplanet Exploration	$176.0	$176.0
Astrophysics Explorer	$144.7	$144.7
James Webb Space Telescope	**$533.7**	**$0.0**
James Webb Space Telescope	$533.7	
James Webb Space Telescope	*$533.7*	
Heliophysics	**$677.8**	**$677.8**
Heliophysics Research	$200.2	$200.2
Living with a Star	$381.0	$381.0
Solar Terrestrial Probes	$37.8	$37.8
Heliophysics Explorer Program	$58.9	$58.9
ICON	*$9.0*	
Other Missions and Data Analysis	*$50.0*	*$58.9*
Aeronautics	**$624.0**	**$624.0**
Education	**$37.3**	**$37.3**
Safety, Security, and Mission Services	**$2,830.2**	**$2,830.2**
Center Management and Operations	**$1,992.5**	**$1,992.5**
Agency Management and Operations	**$837.7**	**$837.7**
Agency Management	$361.2	$361.2
Safety and Mission Success	$171.4	$171.4
Agency IT Services (AITS)	$278.1	$278.1
IT Management	*$26.0*	*$26.0*
Applications	*$59.0*	
Enterprise IT	*$193.1*	*$252.1*
Strategic Capabilities Asset Program	$27.0	$27.0
Construction & Envrmtl Compl Restoration	**$496.1**	**$496.1**
Inspector General	**$39.3**	**$39.3**
NASA TOTAL	**$19,092.2**	**$19,092.2**

NOTE: Chart represents changes in budget structure and does not reflect funding changes.

REBASELINED PROJECTS

In accordance with NPR 7120.5, NASA rebaselined the estimated Life Cycle Costs for the following projects. The original baselines are shown for comparison.

($ in millions)

Webb	Date	Prior	FY16	FY17	FY18	FY19	FY20	BTC	Total
Original Life Cycle Cost	2009	4,448	92	93	94	94	76	66	4,964
Rebaselined Life Cycle Cost	2012	5,990	622	571	540	305	198	610	8,835
Actual	n/a	5,991	620	569					

ICSSat-2	Date	Prior	FY16	FY17	FY18	FY19	FY20	BTC	Total
Original Life Cycle Cost	2013	683	119	27	14	11	6	-	860
Rebaselined Life Cycle Cost	2015	725	141	93	67	14	14	9	1,064
Actual	n/a	730	117	87					

Cost and Schedule Performance Summary

2018 Major Program Annual Report Summary

The 2018 Major Program Annual Report (MPAR) is provided to meet the requirements of section 103 of the NASA Authorization Act of 2005 (P.L. 109-155; 42 U.S.C. 16613). The 2018 MPAR consists of this summary and FY 2019 Congressional Justification pages designated as “Projects in Development,” for the projects outlined below. These project pages constitute each project’s annual report, or if this is the first year for which it is in reporting, the baseline report. The MPAR summary also includes the confidence level of achieving the commitments as requested in the Conference Report accompanying the FY 2010 Consolidated Appropriations Act (P.L. 111-117).

Changes in MPAR Composition since the FY 2018 NASA Budget Estimates

The Landsat-9 project with a baseline development cost of $634.2 million at a joint confidence level of 70 percent is the only new project with estimated lifecycle costs greater than $250 million that received authority to proceed into the development phase since NASA submitted its 2017 MPAR in the FY 2018 NASA Congressional Justification. All of the 2017 MPAR projects in the FY 2018 NASA Congressional Justification are still in development and continue reporting.

Changes in Development Cost and Schedule Estimates from the 2017 MPAR

Five projects (Insight, LCRD, Parker Solar Probe (PSP), Sentinel-6, and SWOT) had no changes in their development cost or schedule estimates over the last year. Additionally, one project is reporting decreases in their development cost, TESS (down -13%), with no change in schedule. While the Mars 2020 and NISAR projects experienced development cost increases of 1% and 3% respectively there is no change to their schedules.

Neither ICESat-2, ICON, nor Webb had any changes in development cost however ICESat-2 had a schedule change of 1 month (change from baseline increased from 3 to 4 months), the schedule of Webb is from March-June 2019 and the schedule for ICON is to be determined. The GRACE-FO project experienced both a development cost decrease (down -6%) and schedule change of 2 months. The SOC project experienced both a development cost decrease (down 3% from last year, now at -18%) and a schedule change that is not yet finalized to September 2020.

There is no change in the development cost or schedule for the InSight project from what was reported in the 2017 MPAR in the FY 2018 NASA Congressional Justification. The 24% development cost increase and the 26 month schedule change were reported to the appropriate Congressional Committees on November 21, 2016.

The EGS project experienced both a development cost increase (up 18%) and schedule change of 13 months. NASA held an Agency Program Management Council (APMC) meeting approving a replan of the EGS project on December 26, 2017. The Agency is currently preparing the appropriate Congressional notifications.

The SLS project experienced both a development cost increase (up 1%) and schedule change of 13 months. NASA held an Agency Program Management Council (APMC) meeting approving a replan of the SLS project on December 26, 2017.

MPAR Summary Table

Figure 1 provides cost, schedule, and confidence level information for NASA projects currently in development with lifecycle cost estimates of $250 million or more. NASA records the estimated development cost and a key schedule milestone and then measures changes from them. NASA tracks one of several key milestones, listed below, for reporting purposes:

Cost and Schedule Performance Summary

- Launch Readiness Date (LRD);
- Full Operational Capability (FOC);
- Initial Operating Capability (IOC); or
- Launch Readiness for EM-1 or EM-2

As a note for clarification, LRD schedule milestones, as reported here, are not typically the launch dates on the NASA launch manifest, but are the desired launch dates as determined by the payload mission and approved by the NASA Flight Planning Board (FPB). A launch manifest is a dynamic schedule that is affected by real world operational activities conducted by NASA and multiple other entities. It reflects the results of a complex process that requires the coordination and cooperation by multiple users for the use of launch range and launch contractor assets. The launch dates shown on the NASA FPB launch manifest are a mixture of confirmed range dates for missions launching within approximately six months and contractual/planning dates for the missions beyond six months from launch. The NASA FPB launch manifest date is typically earlier than the reported schedule dates reported here, thereby allowing for the operationally driven fluctuations to the launch schedule that may be outside of the Project's control. The NASA FPB launch manifest is updated on a periodic basis throughout the year.

Additional explanations for the data in the summary table are provided here:

- Webb: Cost Estimate includes Construction of Facilities funds.
- SOC: The cost of the two instruments is below the $250M LCC threshold for JCL. Independent cost and schedule estimates completed by Aerospace and GSFC RAO with each instrument had confidence levels for cost and schedule that were 70 percent when NASA approved the start of development (at KCP-C).
- EGS-GSDO: The 80% JCL is inferred from analysis based on FY14 President's Budget Request (PBR) including FY14 Appropriation changes. JCL analysis was completed prior to the release of the FY15 PBR. The ABC is informed by the 80% JCL and adjusted to reflect the FY15 PBR budget reduction.
- The Space Launch System (SLS) and Exploration Ground Systems (EGS) – Ground Systems Development Office (GSDO) programs continue to evaluate the impact the following events will have on the EM-1 launch readiness date: 1) the integrated manufacturing, test, and processing schedules based on projection of the ESA service module delivery; 2) the impact of tornado damage recovery at Michoud Assembly Facility and 3) first time production issues for the SLS stages element. NASA will be providing updates to the launch readiness date in the near future.

Additional information on the projects shown in the table below can be found in their individual program and project pages in the main body of the Congressional Justification.

Cost and Schedule Performance Summary

Figure 1: MPAR Summary and Confidence Levels

Project	Base Year	JCL (%)	Development Cost Estimate ($M)		Cost Change (%)	Key Milestone Event	Key Milestone Date		Schedule Change (months)
			Baseline	FY 2018			Baseline	FY 2018	
EGS*	2015	80	1,843.5	2,178.7	18%	LR for EM-1	Nov 2018	Dec 2019	13
GRACE-FO	2015	70	264.0	247.6	-6%	LRD	Feb 2018	Apr 2018	2
ICESat-2	2015	70	763.7	765.1	0%	LRD	Jun 2018	Oct 2018	4
ICON	2015	70	196.0	196.0	0%	LRD	Oct 2017	FY 2018	TBD
InSight	2014	70	541.8	673.5	24%	LRD	Mar 2016	May 2018	26
Landsat-9	2018	70	634.2	634.2	0%	LRD	Nov 2021	Nov 2021	0
LCRD	2017	70	91.8	91.8	0%	LRD	Nov 2019	Nov 2019	0
Mars 2020	2017	70	1,676.9	1,687.6	1%	LRD	Jul 2020	Jul 2020	0
NISAR	2017	70	661.0	683.0	3%	LRD	Sep 2022	Sep 2022	0
Orion**	2016	70	6,768.4	6,572.3	-3%	LR for EM-2	Apr 2023	Apr 2023	0
PSP	2015	70	1,055.7	1,050.3	-1%	LRD	Aug 2018	Aug 2018	0
Sentinel-6	2017	70	465.9	465.9	0%	LRD	Nov 2021	Nov 2021	0
SLS	2015	70	7,021.4	7,058.9	1%	LR for EM-1	Nov 2018	Dec 2019	13
SOC	2014	N/A	376.9	310.0	-18%	LRD	Oct 2018	Feb 2020	TBD
SWOT	2017	80	571.5	571.5	0%	LRD	Apr 2022	Apr 2022	0
TESS	2015	70	323.2	281.4	-13%	LRD	Jun 2018	Jun 2018	0
Webb	2012	66	6,197.9	6,188.8	0%	LRD	Oct 2018	Mar-Jun 2019	TBD

** The 80% JCL is inferred from analysis based on FY14 President's Budget Request (PBR) including FY14 Appropriation changes. JCL analysis was completed prior to the release of the FY15 PBR. The ABC is informed by the 80% JCL and adjusted to reflect the FY15 PBR budget reduction.*

*** Approximately -2% of this amount reflects a transfer of funding to formulation costs and does not represent a reduction in the life cycle cost estimates.*

Launch Readiness (LR) Launch Readiness Date (LRD) Exploration Mission (EM)

FY 2019 PROPOSED APPROPRIATIONS LANGUAGE

DEEP SPACE EXPLORATION SYSTEMS

For necessary expenses, not otherwise provided for, in the conduct and support of exploration research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $4,558,800,000, to remain available until September 30, 2020.

Note.—A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115–56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

EXPLORATION RESEARCH AND TECHNOLOGY

For necessary expenses, not otherwise provided for, in the conduct and support of space technology research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $1,002,700,000, to remain available until September 30, 2020.

Note.—A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115–56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

LEO AND SPACEFLIGHT OPERATIONS

For necessary expenses, not otherwise provided for, in the conduct and support of space operations research and development activities, including research, development, operations, support and services; space flight, spacecraft control and communications activities, including operations, production, and services; maintenance and repair, facility planning and design; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance and operation of mission and administrative aircraft, $4,624,600,000, to remain available until September 30, 2020.

Note.—A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115–56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

FY 2019 PROPOSED APPROPRIATIONS LANGUAGE

SCIENCE

For necessary expenses, not otherwise provided for, in the conduct and support of science research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $5,895,000,000, to remain available until September 30, 2020.

Note.—A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115–56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

AERONAUTICS

For necessary expenses, not otherwise provided for, in the conduct and support of aeronautics research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $633,900,000, to remain available until September 30, 2020.

Note.—A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115–56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

EDUCATION

Unobligated balances previously appropriated under this heading shall be available for purposes of the closure of the Office of Education, including but not limited to, ongoing administration, oversight, monitoring, and funding of grants previously awarded by the Office of Education.

Note.—A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115–56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

SAFETY, SECURITY, AND MISSION SERVICES

For necessary expenses, not otherwise provided for, in the conduct and support of science, aeronautics, space technology, exploration, space operations and education research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; not to exceed $63,000 for official reception and representation expenses; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $2,749,700,000, to remain available until September 30, 2020.

FY 2019 PROPOSED APPROPRIATIONS LANGUAGE

Note.—A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115–56, as amended). The amounts

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

For necessary expenses for construction of facilities including repair, rehabilitation, revitalization, and modification of facilities, construction of new facilities and additions to existing facilities, facility planning and design, and restoration, and acquisition or condemnation of real property, as authorized by law, and environmental compliance and restoration, $388,200,000, to remain available until September 30, 2024: Provided, That proceeds from leases deposited into this account shall be available for a period of 5 years to the extent and in amounts as provided in annual appropriations Acts: Provided further, That such proceeds referred to in the preceding proviso shall be available for obligation for fiscal year 2019 in an amount not to exceed $9,470,300: Provided further, That each annual budget request shall include an annual estimate of gross receipts and collections and proposed use of all funds collected pursuant to section 20145 of title 51, United States Code.
Note.—A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115–56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

INSPECTOR GENERAL

For necessary expenses of the Office of Inspector General in carrying out the Inspector General Act of 1978, $39,300,000, to remain available until September 30, 2020.
Note.—A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115–56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

ADMINISTRATIVE PROVISIONS

Funds for any announced prize otherwise authorized shall remain available, without fiscal year limitation, until the prize is claimed or the offer is withdrawn.

Not to exceed 5 percent of any appropriation made available for the current fiscal year for the National Aeronautics and Space Administration in this Act, or provided for the National Aeronautics and Space Administration under previous appropriations Acts that remain available for obligation or expenditure in fiscal year 2019, may be transferred between such appropriations, but no such appropriation, except as otherwise specifically provided, shall be increased by more than 10 percent by any such transfers. Any such funds transferred to "Construction and Environmental Compliance and Restoration" for construction activities shall not increase that appropriation by more than 20 percent. Balances so transferred shall be merged with and available for the same purposes and the same time period as the appropriations to which transferred. Any transfer pursuant to this provision shall be treated as a reprogramming of funds under section 504 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

The spending plan required by this Act shall be provided by NASA at the theme and program level. The spending plan, as well as any subsequent change of an amount established in that spending plan that meets the notification requirements of section 504 of this Act, shall be treated as a reprogramming under section 504 of this Act and shall not be available for obligation or expenditure except in compliance with the procedures set forth in that section.

ACRONYMS AND ABBREVIATIONS

$K	Dollars in thousands
$M	Dollars in millions
21CSLC	21st Century Space Launch Complex
3U	3-unit
45SW	US Air Force 45th Space Wing
AANAPISI	Asian American and Native American Pacific Islander-Serving Institutions
AAV	Advanced Air Vehicles
ABC	Agency Baseline Commitment
ACC	Advanced Composites Consortium
ACCESS	Advancing Collaborative Connections for Earth System Science
ACCESS-II	Alternative Fuel Effects on Contrails and Cruise Emissions II
ACE	Advanced Composition Explorer (Heliophysics)
ACE	Aerosol, Cloud, and Ecosystems (Earth Science)
ACME	Advanced Combustion via Microgravity Experiments
ACTE	adaptive compliant trailing-edge technology
ADAP	Astrophysics Data Analysis Program
ADCAR	Astrophysics Data Curation and Archival Research
ADS-B	Automatic Dependent Surveillance-Broadcast
AEDL	Advanced Entry Descent and Landing
AES	Advanced Exploration Systems
AFO	Altimetry Follow-On
AFRC	Armstrong Flight Research Center
AFRL	Air Force Research Laboratory
AFTA	Astrophysics Focused Telescope Assets
AIM	Aeronomy of Ice in the Mesosphere
AirMOSS	Airborne Microwave Observatory of Subcanopy and Subsurface
AIRS	Atmospheric Infrared Sounder
AIST	Advanced Information Systems Technology
AITS	Agency Information Technology Services
AMMOS	Advanced Multi-Mission Operations System
AMO	Agency Management and Operations
AMR	Advanced Microwave Radiometer
AO	Announcements of Opportunity
AOSP	Airspace Operations and Safety Program
APL	Applied Physics Laboratory
APMC	Agency Project Management Council
AR	Advanced Radiometer
ARC	Ames Research Center
ARCD	Aerospace Research and Career Development
ARM	Asteroid Redirect Mission

ACRONYMS AND ABBREVIATIONS

ARMD	Aeronautics Research Mission Directorate
ARRA	American Recovery and Reinvestment Act
ARSET	Applied Remote SEnsing Training
ARTEMIS	Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun
ASCENDS	Active Sensing of CO2 Emissions over Nights, Days, and Seasons
ASDM	Astrophysics Decadal Strategic Mission
ASI	Agenzia Spaziale Italiana
ASPERA	Analyzer of Space Plasmas and Energetic Atoms
ATCC	A-Complex Test Control Center
ATD	Air Traffic Management Technology Demonstration-1
ATLAS	Advanced Topographic Laser Altimeter System
ATM	Air Traffic Management
ATTREX	Airborne Tropical TRopopause EXperiment
AU	astronomical units
AURA	Association of Universities for Research in Astronomy
BAA	Broad Agency Announcement
BARREL	Balloon Array for Radiation-belt Relativistic Electron Losses
BEAM	Bigelow Expandable Activity Module
BEDI	Big Earth Data Initiative
BFELoB	Budget Formulation & Execution Lines of Business
BTC	budget to complete
BWG	Beam Wave Guide
CAL	Cold Atom Laboratory
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
CAMMEE	Committee on Aerospace Medicine and the Medicine of Extreme Environments
CAP	Cross-Agency Priority
CARVE	Carbon in Arctic Reservoirs Vulnerability Experiment
CAS	Convergent Aeronautics Solutions
CASIS	Center for the Advancement of Science in Space
CAST	Commercial Aviation Safety Team
CATALYST	Cargo Transportation and Landing by Soft Touchdown
CATS	Cloud Aerosol Transport System
CBT	Computer-Based Training
CCAFS	Cape Canaveral Air Force Station
CCD	charge-coupled device
CCDev2	Commercial Crew Development Round 2
CCM	Camera Control Module
CCMC	Community Coordinated Modeling Center
CCP	Commercial Crew Program

ACRONYMS AND ABBREVIATIONS

CCtCap	Commercial Crew transportation Capabilities
CDC	Centers for Disease Control
CDI	Climate Data Initiative
CDM	Continuous Diagnostic Mitigation
CDR	Critical Design Reviews
CDTI	Center for the Development of Industrial Technology
CECR	Construction and Environmental Compliance and Restoration
CERES	Clouds and the Earth’s Radiant Energy
CFD	Computational Fluid Dynamics
CFOC	Chief Financial Officer’s Council
CGE	Concur Government Edition
CHAMPS™	CubeSat High-Impulse Adaptable Modular Propulsion System™
CHS	Crew Health and Safety
CIBER	Cosmic Infrared Background Experiment Rocket
CINDI	Coupled Ion Neutral Dynamic Investigation
CIRs	co-rotating interaction regions
CL	confidence level
CLARREO	Climate Absolute Radiance and Refractivity Observatory
CMEs	coronal mass ejections
CMO	Center Management and Operations
CMS	Carbon Monitoring System
CNES	Centre National d’Etudes’ Spatiales
CoF	Construction of Facilities
COFAR	Council on Financial Assistance Reform
Comet C-S	Comet Churyumov-Gerasimenko
COR	Cosmic Origins
CoSTEM	committee on science, technology, engineering, and mathematics
COTS	commercial off-the-shelf
CPC	Certification Products Contracts
CPOD	CubeSat Proximity Operations Demonstration
CREAM	Cosmic Ray Energetics and Mass
CRP	Commercialization Readiness Program
CRS	Commercial Resupply Services
CRT	Climate Resilience Toolkit
CRV	current replacement value
CSA	Canadian Space Agency
CSC	Computer Sciences Corporation
CSL	Belgian Centre Spatial de Liège
CSO	Communications Services Office
CSTD	Crosscutting Space Technology Development

ACRONYMS AND ABBREVIATIONS

CYGNSS	Cyclone Global Navigation Satellite System
D&B	Dun and Bradstreet
DAAC	Distributed Active Archive Center
DATA	Digital Accountability and Transparency Act
DCT	Development to Certification Timeline
DESDynI	Deformation, Ecosystem Structure and Dynamics of Ice
DISCOVER-AQ	Deriving Information on Surface Conditions from COlumn and VERtically Resolved Observations Relevant to Air Quality
DLP	Data Loss Prevention
DLR	German Aerospace Center
DLS	deployable launch system
DNA	Deoxyribonucleic acid
DoD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior
DOJ	Department of Justice
DOL	Department of Labor
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DPMC	Directorate Program Management Council
DPR	Dual-frequency Precipitation Radar
DRE	discrete roughness elements
DRIVE	Diversify, Realize, Integrate, Venture, Educate
DSAC	Deep Space Atomic Clock
DSCC	Deep Space Communications Complex
DSCOVR	Deep Space Observatory
DSI	Deutsches SOFIA Institut
DSN	Deep Space Network
DSOC	Deep Space Optical Communication
DSS	Deep Space Station
DUNS	Data Universal Numbering System
ECAST	Expert and Citizen Assessment of Science and Technology
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
ECR	Environmental Compliance and Restoration
eCryo	Evolvable Cryogenics
EFT	Exploration Flight Test
EGS	Exploration Ground Systems
EHRI	Enterprise HR Integration
EHRS	Electronic Health Records System
EICC	EPSCoR Interagency Coordinating Committee
ELV	Expendable Launch Vehicle

ACRONYMS AND ABBREVIATIONS

EM	Exploration Mission
EO-1	Earth Observing-1
EONS	Education Opportunities in NASA STEM
eOPF	electronic Official Personnel Folder
EOS	Earth Observation Systems
EPA	Environmental Protection Agency
EPIC	Earth Poly-Chromatic Imaging Camera
EPSCoR	Experimental Project To Stimulate Competitive Research
EQM	Engineering Qualification Model
ERA	Environmentally Responsible Aviation
ERBS	Earth Radiation Budget Science
ERT	Exploration Research and Technology
ESA	European Space Agency
ESD	Exploration Systems Development
ESDN	Edison Demonstration of Smallsat Networks
ESM	Earth Systematic Missions
ESSP	Earth System Science Pathfinder
ESTEEM	Earth Systems, Technology and Energy Education for MUREP
ESTO	Earth Science Technology Office
ESTP	Earth Science Technology Program
ETD	Exploration Technology Development
ETS2	E-Gov Travel Service 2
EUL	Enhanced Use Leasing
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUS	Exploration Upper Stage
EVI	Earth Venture Instruments
EVM	Earth Venture small Missions
EX	Explorers
FAA	Federal Aviation Administration
FDC	Flight Demonstrations and Capabilities
FDMS	Federal Docket Management System
FFATA	Federal Funding Accountability and Transparency Act
FFI	Forsvarets Forskning Institute
FGS	Fine Guidance Sensor
FIRST	For Inspiration and Recognition of Science and Technology
FIT	Financial Innovation and Transformation
FMLoB	Financial Management Lines of Business
FO	Follow-On
FOC	Full operational capability
FPB	Flight Planning Board

ACRONYMS AND ABBREVIATIONS

FPI	Fast Plasma Investigation
FPPS	Federal Personnel and Payroll System
FRR	Flight Readiness Review
FY	Fiscal Year
G-3	Gulfstream 3
GALEX	Galaxy Evolution Explorer
GCIS	Global Change Information System
GEDI	Global Ecosystem Dynamics Investigation Lidar
GEMS	Gravity and Extreme Magnetism
GEO-CAPE	GEOstationary Coastal and Air Pollution Events
GFZ	German Research Centre for Geosciences
GIS	Geographic Information System
GLOBE	Global Learning and Observations to Benefit the Environment
GMAO	Global Modeling and Assimilation Office
GNC	Guidance, Navigation, and Control
GOLD	Global-scale Observations of the Limb and Disk
GPM	Global Precipitation Measurement
GPS	Global Positioning System
GPSP	Global Positioning System-Payload
GRACE	Gravity Recovery and Climate Experiment
GRAIL	Gravity Recovery and Interior Laboratory
GRC	Glenn Research Center
GRC-PBS	Glenn Research Center Plum Brook Station
GRIFEX	GEO-CAPE Readout Integrated Circuit Experiment
GSA	General Services Administration
GSDO	Ground Systems Development and Operations Program Office
GSFC	Goddard Space Flight Center
GSRT	GSFC System Review Team
HAWC+	High-resolution Airborne Wideband Camera
HBCU	Historically Black Colleges and Universities
HECC	High End Computing Capability
HEEET	Heat shield for Extreme Entry Environment Technology
HEO	Human Exploration and Operations
HEOMD	Human Exploration and Operations Mission Directorate
HF	High Frequency
HHS	Department of Health and Human Services
HIAD	Hypersonic Inflatable Aeroshell Decelerator
HICO	Hyperspectral Imager for the Coastal Ocean
HIS	Heavy Ion Sensor
HITL	Human-In-The-Loop

ACRONYMS AND ABBREVIATIONS

HMI	Helioseismic and Magnetic Imager
HMTA	Health and Medical Technical Authority
HMV	Heavy Maintenance Visit
HP3	Heat Flow and Physical Properties Package
HQ	Headquarters
HR	Human resources
HRP	Human Research Program
HS-3	Hurricane and Severe Storm Sentinel
HSFO	Human Space Flight Operations
HSI	Hispanic-Serving Institutions
HVAC	Heating, Ventilating, and Air Conditioning
HyspIRI	Hyperspectral and Infrared Imager
I&T	Integration & Test
I3P	Infrastructure Integration Program
IAA	Interagency Agreement
IADS	Integrated Arrival/Departure/Surface
IAE	Integrated Acquisition Environment
IASP	Integrated Aviation Systems Program
IBEX	Interstellar Boundary Explorer
ICESat-2	Ice, Cloud, and land Elevation Satellite-2
ICON	Ionospheric Connection Explorer
IDIQ	indefinite-delivery-indefinite-quantity
IDS	Intrusion Detection Systems
ILT	Instructor-Led Training
IMC	International Mission Contributions
InSight	Investigations, Geodesy and Heat Transport
INTA	National Institute of Aerospace Technology
InVEST	In-space Validation of Earth Science Technology
IOC	Initial operating capability
IPAO	Independent Program Assessment Office
IPCC	Intergovernmental Panel on Climate Change
IR	Infrared
IRIS	Interface Region Imaging Spectrograph
IRS	Internal Revenue Service
ISARA	Integrated Solar Array and Reflectarray Antenna
ISCM	Information Security Continuous Monitoring
ISERV	ISS SERVIR Environmental Research and Visualization System
ISIM	Integrated Science Instrument Module
ISRO	Indian Space Research Organisation
ISRS	In-Space Robotic Servicing

ACRONYMS AND ABBREVIATIONS

ISRU	in-situ resource utilization
ISS	International Space Station
IT	information technology
I-trek	I turn research into empowerment and knowledge
ITSEC-EDW	IT Security Enterprise Data Warehouse
IV&V	Independent Verification and Validation
JAXA	Japanese Aerospace Exploration Agency
JCL	Joint Confidence Level
JEL	jacking, equalizing, and leveling
JEM-EF	Japanese Experiment Module – Exposed Facility
JHU	Johns Hopkins University
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JSC	Johnson Space Center
JUICE	Jupiter Icy Moons Explorer
JWST	James Webb Space Telescope
KaBOOM	Ka-Band Objects Observation and Monitoring
KaRIn	Ka-band Radar Interferometer
KBOs	Kuiper Belt objects
KDP	Key Decision Point
KOA	Keck Observatory Archive
KSC	Kennedy Space Center
LADEE	Lunar Atmosphere and Dust Environment Explorer
LaRC	Langley Research Center
LBTI	Large Binocular Telescope Interferometer
LC	Launch Complex
LCC	Life Cycle Cost
LCPSO	Land Cover Project Science Office
LCRD	Laser Communications Relay Demo
LDCM	Landsat Data Continuity Mission
LDSD	Low Density Supersonic Decelerator
LEARN	Leading Edge Aeronautics Research for NASA
LED	Light-Emitting Diode
LEED	Leadership in Energy and Environmental Design
LEO	Low Earth Orbit
LH2	Liquid Hydrogen
LIDAR	Light Detection and Ranging
LIS	Lightning Imaging Sensor
LISA	Laser Interferometer Space Antenna
LLCD	Lunar Laser Communication Demonstration

ACRONYMS AND ABBREVIATIONS

LMSSC	Lockheed Martin Space Systems Company
LoB	Lines of Business
LOX	liquid oxygen
LRA	Laser Retro-reflector Assembly
LRD	Launch Readiness Date
LRO	Lunar Reconnaissance Orbiter
LRR	Launch Readiness Review
LVC-DE	Live Virtual Constructive-Distributed Environment
LWS	Living With a Star
MAA	MUREP Aerospace Academy
MAF	Michoud Assembly Facility
MAIANSE	MUREP for American Indian and Alaskan Native STEM Engagement
MARSIS	Mars Advanced Radar for Subsurface and Ionospheric Sounding
MAVEN	Mars Atmosphere and Volatile EvolutioN
MCI	Minority University Research and Education Program Community College Curriculum Improvement
MCR	Mission Concept Review
MDR	Mission Design Review
MEaSUREs	Making Earth System data records for Use in Research Environments
MEDLI	Mars Entry, Descent, and Landing Instrumentation
MEI	Minority University Research and Education Program Educator Institute
MER	Mars Exploration Rover
MERLIN	Mesoscale Eastern Range Lightning Information Network
MERRA	Modern Era Retrospective-analysis for Research and Applications
MESSENGER	MErcury Surface, Space ENvironment, GEochemistry, and Ranging
MIDEX	Medium-Class Explorers
MIRI	Mid Infrared Instrument
MIRO	MUREP Institutional Research Opportunity
MIs	minority institutions
MIT	Massachusetts Institute of Technology
MLCC	multi-layer ceramic capacitor
MLTI	mesosphere-lower thermosphere-ionosphere
MMOD	MicroMeteoroid and Orbital Debris
MMS	Magnetospheric Multiscale
MO	Missions of Opportunity
MO&I	Mission Operations and Integration
MODIS	Moderate Resolution Imaging Spectroradiometer
MOM	Mars Orbiter Mission
MOMA-MS	Mars Organic Molecule Analyzer Mass Spectrometer
MOO	Multi-Mission Operations

ACRONYMS AND ABBREVIATIONS

MOXIE	Mars Oxygen ISRU Experiment
MPAR	Major Program Annual Report
MPCV	Multi-Purpose Crew Vehicle
MPRAT	Mission Profile Risk Assessment Test
MRO	Mars Reconnaissance Orbiter
MSE	MUREP STEM Engagement
MSFC	Marshall Space Flight Center
MSI	Minority-Serving Institutions
MSL	Measurement Systems Laboratory
mths	months
MUREP	Minority University Research and Education Program
MUSES	Multi-User System for Earth Sensing
MUSS	Multi User Systems and Support
N/A	not applicable
NAC	National Agency Check
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NCCS	NASA Center for Climate Simulations
NCRP	National Council on Radiation Protection
NEACC	NASA Enterprise Applications Competency Center
NEN	Near Earth Network
NEO	near-Earth objects
NEOO	Near-Earth Object Observations
NESC	NASA Engineering and Safety Center
NextGen	Next Generation Air Transportation System
NHPA	National Historic Preservation Act
NIAC	NASA Innovative Advanced Concepts
NICER	Neutron star Interior Composition ExploreR
NIFS	NASA Internship, Fellowship, and Scholarship
NIH	National Institutes of Health
NIRCam	Near Infrared Camera
NIRISS	Near Infrared Imager and Slitless Spectrograph
NISAR	NASA-ISRO Synthetic Aperture Radar
NISN	NASA Integrated Services Network
NIST	National Institute of Standards and Technology
NLCs	noctilucent clouds
NLS	United Launch Services
NMO	NASA Management Office
NOAA	National Oceanographic and Atmospheric Administration
NOx	mono nitrogen oxide

ACRONYMS AND ABBREVIATIONS

NPP	National Polar-orbiting Partnership
NRA	NASA Research Announcement
NRC	National Research Council
NREP	NanoRacks Exposure Platform
NRPTA	National Rocket Propulsion Test Alliance
NSBRI	National Space Biomedical Research Institute
NSF	National Science Foundation
NSSC	NASA Shared Services Center
NSSDC	National Space Science Data Center
NSTP PPD	National Space Policy Launch Infrastructure and Modernization Plan
NuSTAR	Nuclear Spectroscopic Telescope Array
O&M	operations and maintenance
OA	Office of Audits
OCAMS	OSIRIS-REx Camera Suite
OCHMO	Office of Chief Health Medical Officer
OCO	Orbiting Carbon Observatory
OCSD	Optical Communications and Sensor Demonstration
OCT	Office of the Chief Technologist
OE	Office of Education
OI	Office of Investigations
OIG	Office of Inspector General
OLA	OSIRIS-REx Laser Altimeter
OLI	Operational Land Imager
OMB	Office of Management and Budget
OMDA	Other Missions and Data Analysis
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapping and Profiler Suite
ONERA	French Office National d'Etudes et Recherches Aérospatiales
OPM	Office of Personnel Management
Orb-#	Orbital Sciences Commercial Resupply Services #
ORR	Operational Readiness Review
OSC	Orbital Sciences Corporation
OSHA	Occupational Safety and Health Administration
OSIRIS-REx	Origins Spectral Interpretation Resource Identification and Security-Regolith Explorer
OSMA	Office of Safety and Mission Assurance
OSTM	Ocean Surface Topography Mission
OSTST	Ocean Surface Topography Science Team
OTE	Optical Telescope Element
OTES	OSIRIS-REx Thermal Emission Spectrometer

ACRONYMS AND ABBREVIATIONS

OVIRS	OSIRIS-REx Visible and Infrared Spectrometer
OVWST	Ocean Vector Winds Science Team
PACE	Pre-Aerosol, Clouds, and ocean Ecosystem
PAMSS	Planetary Atmosphere Minor Species Sensor
Pan-STARRS	Panoramic Survey Telescope and Rapid Reporting System
PB	President's Budget
PCA	Physicians' comparability allowance
PCOS	Physics of the Cosmos
PDA	progressive damage analysis
PDR	preliminary design review
PDS	Planetary Data System
PEP	Particle Environment Package
PI	Principal Investigator
PIR	Program Implementation Review
PIV	Personal Identity Verification
P.L.	Public Law
POWER	Protecting Our Workers and Ensuring Reemployment
PSL	Propulsion Systems Laboratory
Pu	plutonium
PV	Planetary Ventures, LLC
QM-1	qualification motor 1
QuikSCAT	Quick Scatterometer
R&D	Research and Development
R&T	Research and Technology
RAD	Radiation Assessment Detector
RAIF	Research Aircraft Integration Facility
RAO	Right Anterior Oblique
RAP	Robotics Alliance Project
RBA	Reflector Boom Assembly
RBI	Radiation Budget Instrument
REDD	Reducing Emissions from Deforestation and forest Degradation
RESOLVE	Regolith and Environment Science and Oxygen and Lunar Volatiles Extraction
REXIS	Regolith X-ray Imaging Spectrometer
RF	radio frequency
RFU	Radio Frequency Unit
RHESSI	Ramaty High Energy Solar Spectroscopic Imager
RID	Research Infrastructure Development
RIME	Radar for Icy Moons Exploration
RISE	Rotation and Interior Structure Experiment
ROD	Record of Decision

ACRONYMS AND ABBREVIATIONS

ROSES	Research Opportunities in Space and Earth Sciences
RPO	rendezvous and proximity operations
RPS	Radioisotope Power Systems
RPT	Rocket Propulsion Testing
RRM	Robotic Refueling Mission
RRS	Research Range Services
RS	Reflected Solar
RTCA	Radio Technical Commission for Aeronautics
RTG	Radioisotope Thermoelectric Generator
RVLT	Revolutionary Vertical Lift Technology
SAC-D	Satellite for Scientific Applications-D
SAFFIRE	Spacecraft Fire Experiment
SAGE	Stratospheric Aerosol and Gas Experiment
SAM	Sample Analysis at Mars (Planetary Science)
SAM I	Stratospheric Aerosol Measurement (Earth Science)
SAO	Smithsonian Astrophysical Observatory
SAR	Synthetic Aperture Radar
SARDA	Spot and Runway Departure Advisor
SASO	Safe Autonomous Systems Operations
SBA	Small Business Administration
SBIR	Small Business Innovation Research
SCaN	Space Communications and Navigation
SCAP	Strategic Capabilities Asset Program
SDO	Solar Dynamics Observatory
SDR	System Design Review
SEA	STEM Education and Accountability
SEAP	STEM Education and Accountability Projects
SEIS	Seismic Experiment for Interior Structure
SEP	Solar Electric Propulsion
SERENA	Search for Exospheric Refilling and Emitted Natural Abundances
SET	Space Environment Testbeds
SETAG	Space Environmental Testing Assets Group
SEWP	Solutions for Enterprise-Wide Procurement
SEXTANT	Station Explorer X-ray Timing and Navigation Technology
SFCO	Space Flight Crew Operations
SFS	Space and Flight Support
SGP	Space Geodesy project
SGSS	Space Network Ground Segment Sustainment
SIM	Spectral Irradiance Monitor
SIPS	Science Investigator-led Processing Systems

ACRONYMS AND ABBREVIATIONS

SIR	System Integration Review
SL-8	SpaceLoft-8
SLI	Sustainable Land Imaging
SLPSRA	Space Life and Physical Sciences Research and Applications
SLPSRAD	Space Life and Physical Sciences Research and Applications Division
SLS	Space Launch System
SMA	Safety and Mission Assurance
SMAP	Soil Moisture Active/Passive
SMART NAS	Shadow Mode Assessments Using Realistic Technologies for the National Airspace System
SMD	Science Mission Directorate
SMEX	Small Explorers
SMS	Safety and Mission Success
SNC	Sierra Nevada Corporation
SOC	Solar Orbiter Collaboration
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOHO	Solar and Heliospheric Observatory
SoloHI	Solar Orbiter Heliospheric Imager
SORCE	Solar Radiation and Climate Experiment
SOST	Subcommittee on Ocean Science and Technology
SOT	Solar Optical Telescope
Space Grant	National Space Grant College and Fellowship Program
SpaceX	Space Exploration Technologies Company
SPB	Solar Pressure Balloon
SPDF	Space Physics Data Facility
SPHERES	Synchronized Position Hold, Engage, Reorient, and Experimental Satellites
SPOC	Science Processing and Operations Center
SPP	Solar Probe Plus
SpX-#	Space Exploration Technologies Company Commercial Resupply Services #
SR&T	Strategic Research and Technology
SRB	Strategic Review Board
SRC	Sample Return Capsule
SRP	supersonic retrorocket propulsion
SRR	Systems Requirement Review
SSC	Stennis Space Center
SSERVI	Solar System Exploration Research Virtual Institute
SSFL	Santa Susana Field Laboratory
SSL	Space Systems Loral
SSMS	Safety, Security, and Mission Services
ST	Space Technology

ACRONYMS AND ABBREVIATIONS

STEM	science, technology, education, and mathematics
STEREO	Solar TErrestrial RElations Observatory
STIP	Strategic Technology Investment Plan
STMD	Space Technology Mission Directorate
STP	Solar Terrestrial Probes
STPH-5 LIS	Space Test Program Houston-5 Lightning Imaging System
STScI	Space Telescope Science Institute
STTR	Small Business Technology Transfer
SWEAP	Solar Wind Electrons Alphas and Protons
SWOT	Surface Water Ocean Topography
SwRI	Southwest Research Institute
SXS	Soft X-Ray Spectrometer
TAC	Transformative Aeronautics Concepts
TAGSAM	Touch and Go Sample Acquisition Mechanism
TASEAS	Technologies for Assuring Safe Energy and Attitude State
TBD	to be determined
TBW	truss-braced wing
TCTE	Total Solar Irradiance Calibration Transfer Experiment
TCU	Tribal Colleges and Universities
TDM	Technology Demonstration Missions
TDRS	Tracking and Data Relay Satellite
TDT	Transonic Dynamics Tunnel
TEMPO	Tropospheric Emissions: Monitoring of Pollution
TESS	Transiting Exoplanet Survey Satellite
TFM	Traffic Flow Management
TGO	Trace Gas Orbiter
THEMIS	Time History of Events and Macroscale Interactions during Substorms
THOR	Terrestrial HIAD Orbital Reentry
TIM	Total Irradiance Monitor
TIMED	Thermosphere Ionosphere Mesosphere Energetics and Dynamics
TIR-FFD	Thermal-Infrared Free-Flyer
TIRS	Thermal Infrared Sensor
TMC	Technical and Management and Cost
TPS	Thermal Protection System
TR&T	Targeted Research & Testing
TRACT	Transport Rotorcraft Airframe Crash Testbed
TRL	Technology Readiness Level
TRMM	Tropical Rainfall Measurement Mission
TSI	total solar irradiance
TSIS	Total and Spectral Solar Irradiance Sensor

ACRONYMS AND ABBREVIATIONS

TSS	Terminal Sequencing and Spacing
TTT	Transformational Tools and Technologies
TWINS	Two Wide-angle Imaging Neutral-atom Spectrometers
UAS	Unmanned Aircraft Systems
UAV	unmanned aerial vehicle
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
UHB	ultra-high bypass
UHF	ultra high frequency
UKSA	United Kingdom Space Agency
ULA	United Launch Alliance
ULS	United Launch Services
UNEX	University-Class Explorers
UPSS	universal propellant servicing system
UPTWT	Unitary Plan Wind Tunnel
USAF	United States Air Force
USAID	U.S. Agency for International Development
U.S.C.	United States Code
USGCRP	US Global Change Research Program
USGS	US Geological Survey
USRA	Universities Space Research Association
UTM	UAS Traffic Management
UVS	Ultraviolet Spectrograph
VAB	Vehicle Assembly Building
VAC	Vertical Assembly Center
VAFB	Vandenberg Air Force Base
VIIP	visual impairment/intra-cranial pressure
VIIRS	Visible Infrared Imaging Radiometer
VIL	Vehicle Integration and Launch
VSPT	Variable-Speed Power Turbine
WANs	Wide Area Networks
WASP	Web Application Security Program
WBS	work breakdown structure
WCF	Working Capital Fund
Webb	James Webb Space Telescope
WFA	Work from Anywhere
WFF	Wallops Flight Facility
WFIRST	Wide-Field Infrared Survey Telescope
WISE	Wide-field Infrared Survey Explorer
WISPR	Wide-field Imager for Solar PRobe
WSTF	White Sands Test Facility

ACRONYMS AND ABBREVIATIONS

XMM-Newton	X-ray Multi-Mirror Mission
ZBOT	Zero Boil-Off Tank