



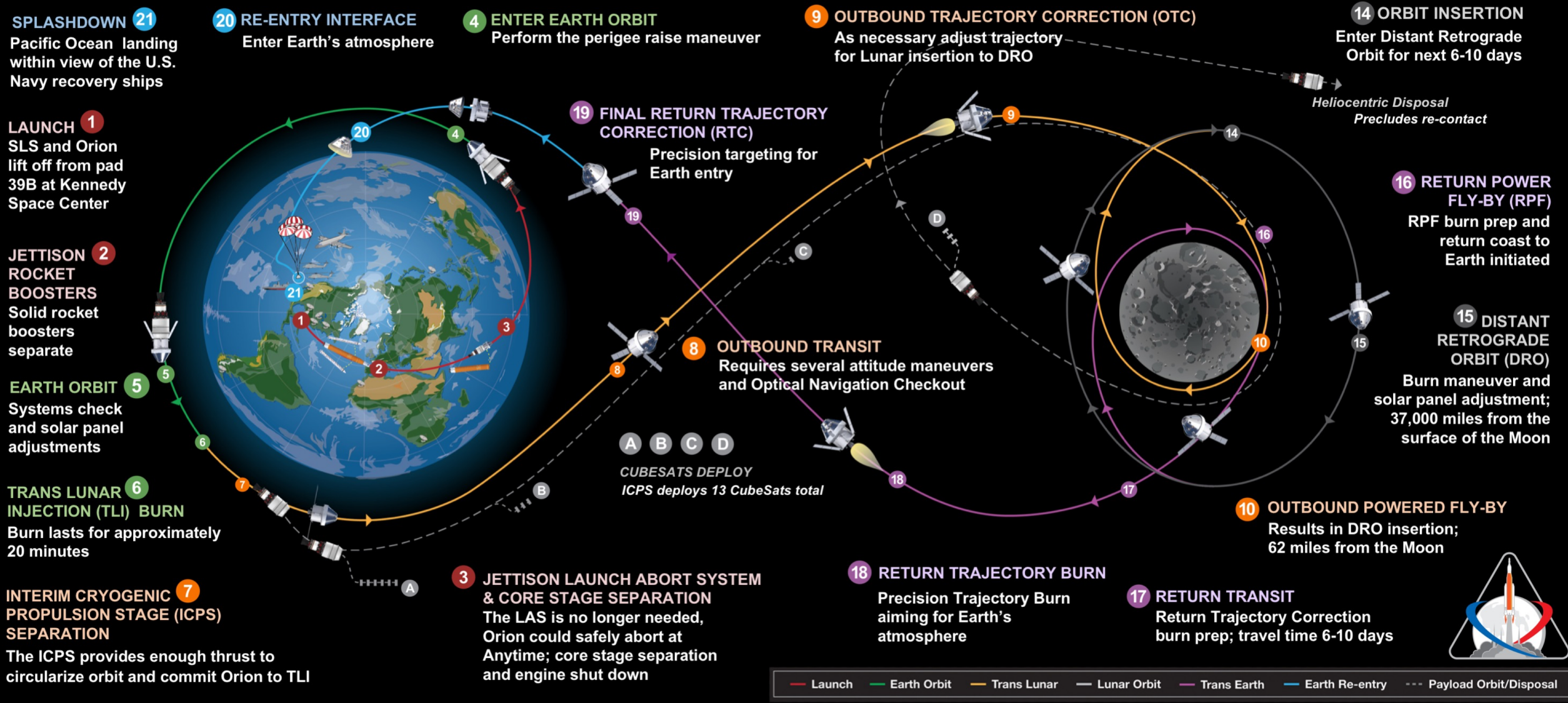
Exploration Systems Development Update

Bill Hill, Deputy Associate Administrator for Exploration Systems Development

NASA Advisory Council – August 27, 2018

EXPLORATION MISSION-1

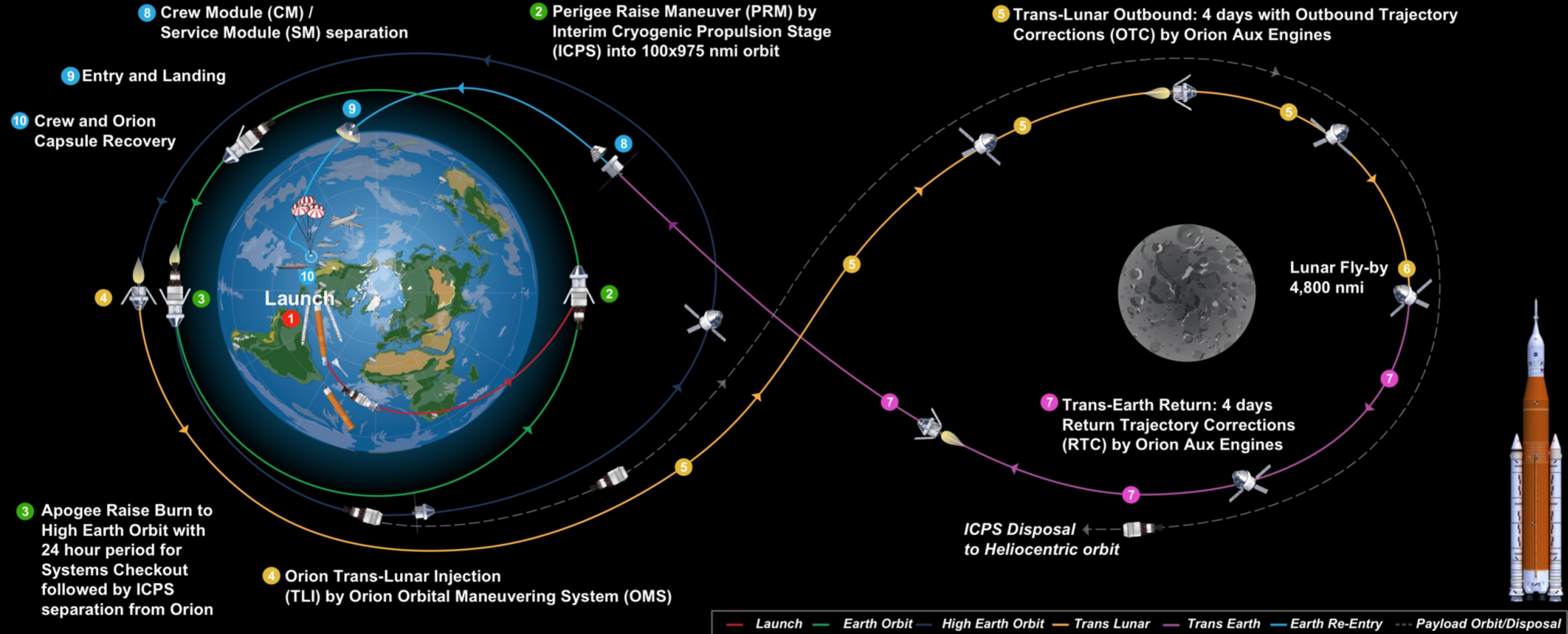
The first uncrewed, integrated flight test of NASA's Orion spacecraft and Space Launch System rocket, launching from a modernized Kennedy spaceport



Total distance traveled: 1.3 million miles – Mission duration: 25.5 days – Re-entry speed: 24,500 mph (Mach 32) – 13 CubeSats deployed

EXPLORATION MISSION-2

Crewed Hybrid Free Return Trajectory, demonstrating crewed flight and spacecraft systems performance beyond Low Earth Orbit (LEO)

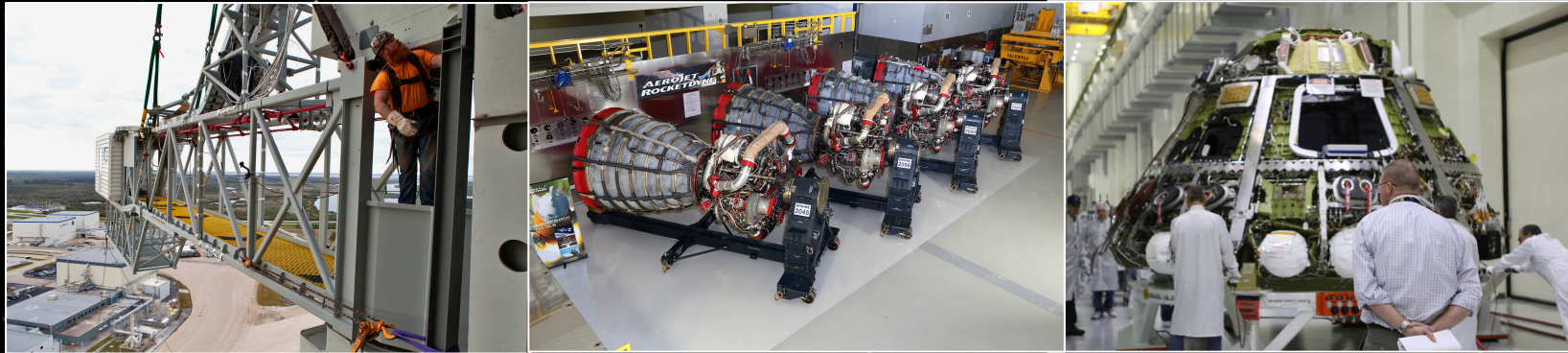


SLS Configuration (Block 1) with Human Rated ICPS | 22x975 nmi (40.7x1806 km) insertion orbit | 28.5 deg inclination

4 astronauts | Total distance traveled: 1,090,320 km – Mission duration: 9 Days – Re-entry speed: 24,500 mph (Mach 32)

Building to Exploration Mission-1 (EM-1)

European Service Module Critical Design Review ✓	LVSA Manufacturing Complete ✓	Core Stage Green Run Hot Fire Test
Crew Module Pressure Proof Test ✓	Mobile Launcher (ML) Umbilicals Installed ✓	Crew and Service Module Delivery to EGS
Booster Qualification Motor 2 Test ✓	VAC Welding Complete on Core Stage ✓	Ground Flight Application Software Complete
Crew Module Propellant Pressure Proof Test ✓	Launch Pad Flame Trench Construction Complete ✓	Booster Stacking in VAB
VAB Verification & Validation Complete ✓	European Service Module Delivered to KSC	Core Stage Arrival at KSC
RS-25 Flight Engines Complete ✓	All Underway Recovery Tests Complete	Core Stage Stacking with Boosters in VAB
ICPS Delivered to KSC ✓	Crew Module and Service Module Mate	CM/SM Mating with Launch Abort System
Crew Module Initial Power On ✓	All Parachute Tests Complete	Orion Mating with SLS in VAB
VAB High Bay Construction Complete ✓	Core Stage Integration	Wet Dress Rehearsal at Launch Pad
Multi-Payload Processing Facility Construction ✓	ML Ground Support Equipment Installation Complete	Roll-out for Launch



Orion Spacecraft Status

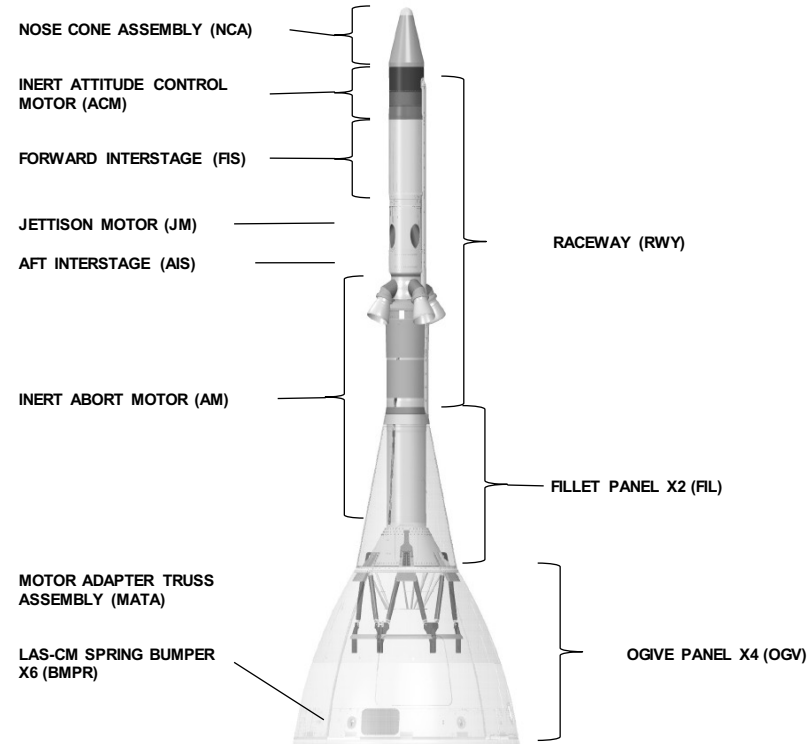


EM-1 and Ascent Abort (AA)-2 Launch Abort System (LAS) (Lockheed)

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- ✓ LAS EM-1 Fillets & Ogive panels delivered to Micoud Assembly Facility (MAF) - November 2017
- ✓ EM-1 LAS Fairing Assembly Components - February thru July 2018 (ship in place)
- AA-2 LAS Abort Motor On Dock (O/D) KSC - August 2018
- AA-2 LAS Jettison Motor (JM) O/D KSC - September 2018
- AA-2 LAS Attitude Control Motor O/D KSC - November 2018
- EM-1 LAS Jettison Motor delivery available - November 2018 (ship in place)
- AA-2 LAS Fairing Assembly Components O/D KSC - August thru December 2018
- AA-2 Launch - April 2019



Graphical Representation of LAS During AA-2 Test



Viewing the AA-2 Crew Module Test Article

Ogive & Fillet Panels Fabrication complete

EM-1 Fairing components available

EM-1 Jettison Motor Available

AA-2 Fairing components O/D KSC

AA-2 Motors O/D KSC

AA-2 Launch

EM-1 Crew Module (CM) (Kennedy Space Center Operations & Checkout Building)

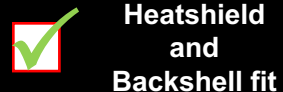
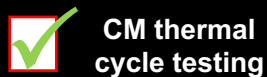
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- ✓ CM module level test completed - November 2017
 - ✓ 28 test procedures, functionally tested all systems
- ✓ CM thermal cycle testing completed - December 2017
 - ✓ 2 full cycles, 28F to 127F
- ✓ Heatshield and Backshell fit ups completed - January 2018
- ✓ Heatshield painting and fitcheck completed - February 2018
- ✓ Propylene Glycol Water (PGW) accumulator R&R
- ✓ Heatshield Installation – August 2018
 - Reinstall reworked avionics (hybrid issue) – (troubleshooting last component)
 - Side Hatch installation & leak tests - September 2018
 - CM Direct Field Acoustics Test (DFAT) – November 2018
 - CM Complete - December 2018
 - CM/Service Module (SM) Mate - March 2019



EM-1 Heat Shield Installation at KSC



EM-1 Crew Module Adapter (CMA) (KSC O&C Building)

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- ✓ CMA subsystem integration completed - September 2017
- ✓ CMA end-to-end testing completed - December 2017
- ✓ Temp installation of Star Trackers - April 2018
- ✓ Install T-0 flight plate - April 2018
- ✓ Reinstall reworked avionics (hybrid issue) - May 2018
- Complete functional retests - August 2018
- Ready to mate with European Service Module (ESM) - September 2018



EM-1 CMA in Clean Room



CMA subsystem integration



CMA assembly operations and end-to-end testing



Install T-0



Install reworked avionics



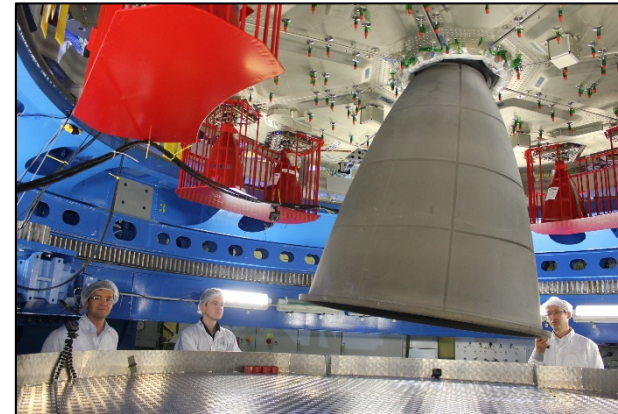
Complete functional tests

EM-1 Service Module (ESM) (Bremen, Germany)

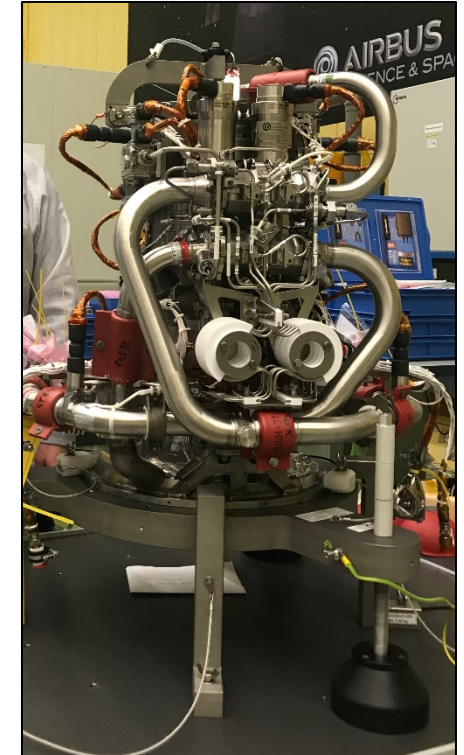
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- ✓ Installed ESM Thermal Control Unit (TCU) - June 2017 (R&R Board)
- ✓ Installed ESM Reaction Control System (RCS) Thruster - October 2017
- ✓ Pressurant Control Assembly (PCA) valves delivered to Bremen – March 2018
- ✓ RCS Flow Control Valve (FCU) Welds
- ✓ ESM Power Control and Distribution Unit (PCDU) deliveries:
 - ✓ PCDU #1 – (EM-4 then PCDU #3)
 - ✓ PCDU #2 – (PCDU temp install, then PCDU#1)
- ✓ ESM N2 Tank installed - March 2018
- ✓ ESM Prop Tanks installed - March 2018
- ✓ ESM Orbital Maneuvering System Engine (OMS-E) installed - March 2018
- ✓ ESM Consumable Storage System (CSS) test complete - April 2018
- ✓ ESM PCA final integration complete - April 2018
- ✓ ESM Functional tests, March - June 2018
- ESM N2 Tank Switched – August 2018
- ESM on dock at KSC - September 2018
- Step-1 Propellant Qualification Motor (PQM) testing complete - October 2018



Service Module Nozzle Move Test



*ESM-1 OMS Engine
Prior to Installation*



EM-1 CMA/ESM (KSC O&C Building)

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Integration Ops & Tests (KSC)

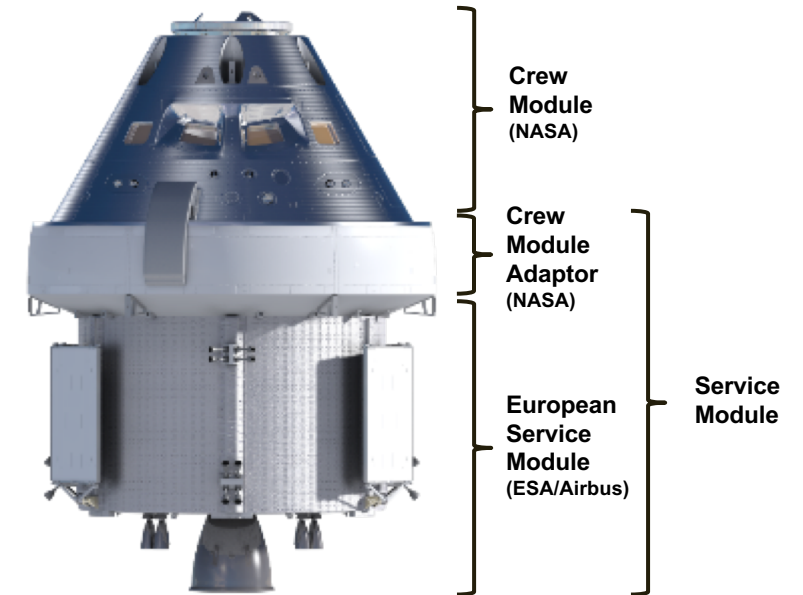
- CMA Ready to Mate - September 2018
- SM Delivery to KSC - September 2018
- CMA/ESM mate - October 2018
- CMA/ESM proof/leak test – November 2018
- SM initial power up and functional tests - November 2018 to December 2018
- SM thermal cycle test - December 2018
- SM Direct Field Acoustics Test (DFAT) - February 2019
- CM/SM Mate - March 2019

Testing (Plum Brook)

- CM/SM Transport to Plum Brook - May 2019
- CM/SM Environmental Testing (thermal vac, thermal balance, EMI/EMC) complete - September 2019
- CM/SM Transport to KSC - September 2019

Final Work (KSC)

- CM/SM Complete - November 2019
- CM/SM Turnover to EGS - November 2019



CMA/ESM Mate



CMA/ESM proof/leak test



SM initial power up/ functional tests



SM thermal cycle test



SM DFAT



CM/SM Mate

Flight Software/Integrated Test Lab (Lockheed Martin/Denver)

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Software Development

- ✓ Flight Software load 28A released on 9/14/17 (Nominal Mission including On-Orbit, CM Fault Detection Isolation and Recovery (FDIR) except prop)
- ✓ Flight Software load 28B released on 12/19/17 (CM prop FDIR, EM-1 Onboard Network Config, Solar Array Control)
- ✓ Flight Software load 28C released 3/08/18 (Guidance, Navigation, and Control (GNC) commands, Ballistic Entry, Initial ESM FDIR, Video, Burn Plan Management)
- ✓ Flight Software load 28D released 5/31/18 (ESM FDIR, Ascent Aborts, Initial Backup Flight Software (BFS)/Safe Mode, Optical Navigation)
- ✓ Flight Software 28D-Patch 1 released on 6/28/18
- Flight Software load 28E on schedule for 9/20/18 (Full GNC SM FDIR, BFS/Safe Mode, Redundancy Management)

28A/B FSW
Released

28C FSW
Release

28D FSW
Release

28D-Patch
1 Release

28E FSW
Release

Integrated Test Lab (ITL)

- ✓ Completed 18 Nominal, Off Nominal and FDIR mission tests thru 2017
- ✓ ITL-03 CM Subsystem Integration & Assembly, Test, and Launch Operations (ATLO) Check out (C/O) ITL gap testing complete - February 2018
- ATLO IPO & CSM 28D functional testing complete - September 2018
- ATLO mission & CSM 28E testing complete - December 2018
- CSM 28F testing complete - February 2019
- ITL Test Campaign verification testing complete - August 2019

Gap testing

28D functional
testing

28E mission
testing

CSM testing
complete

ITL Test
Campaign
Verif complete

EM-2 Orion Spacecraft Progress

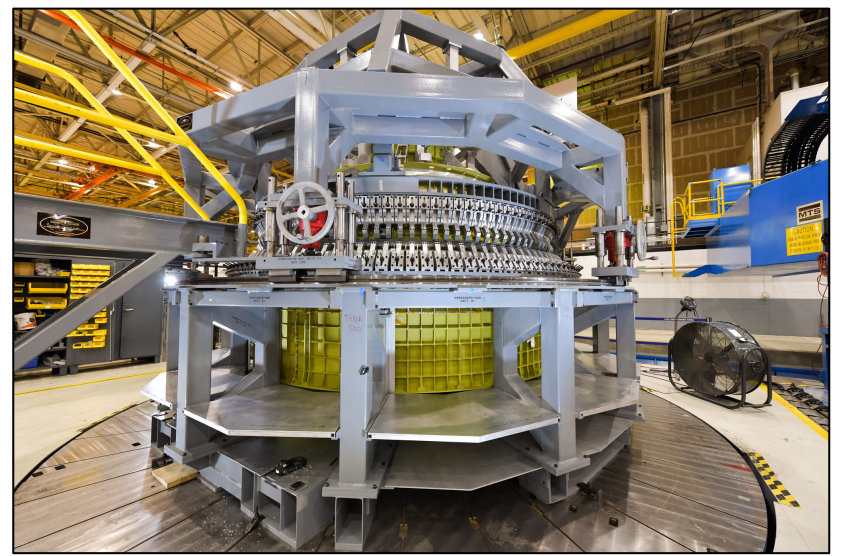
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EM-2 Pressure Vessel

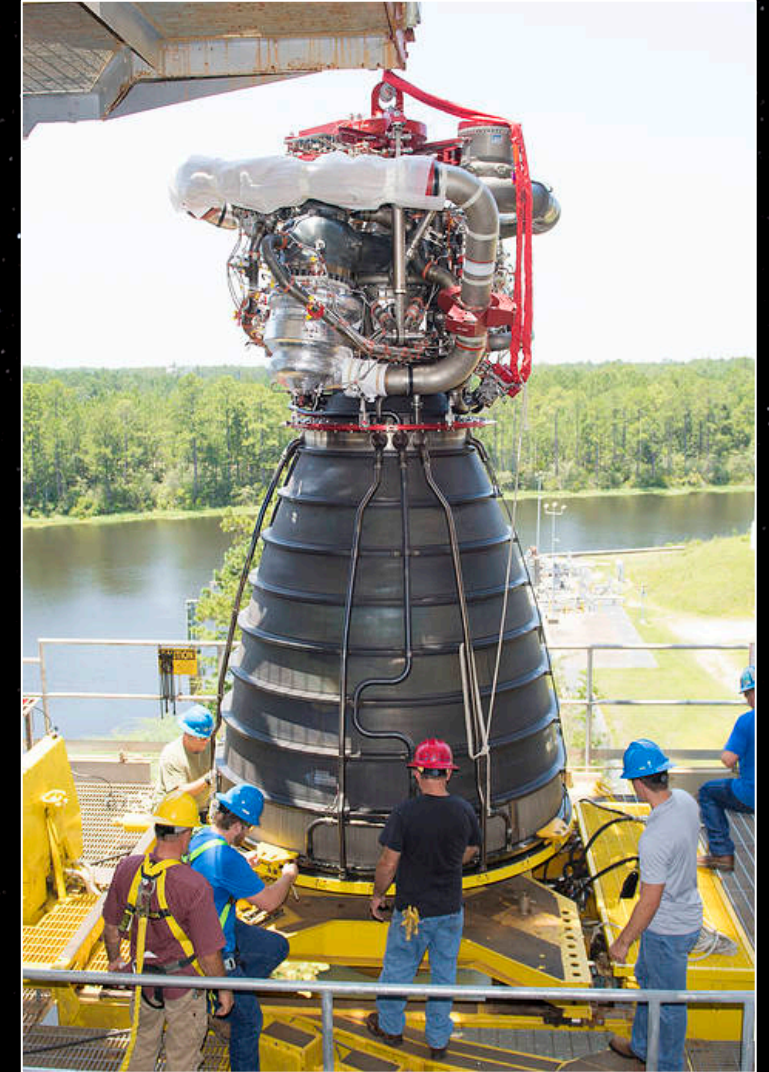
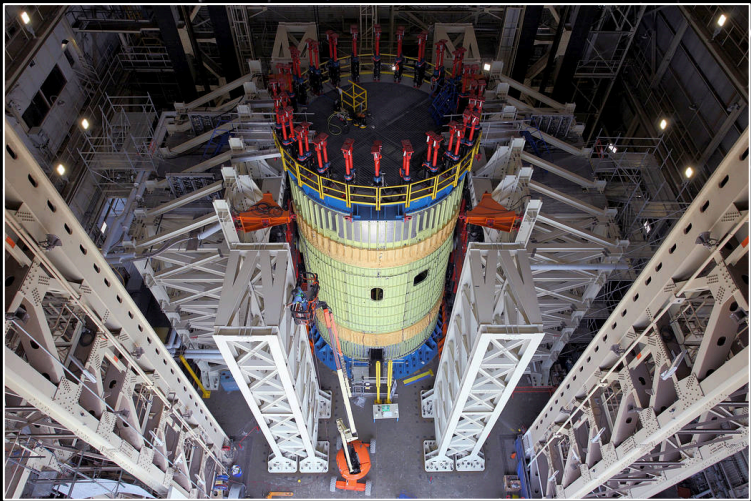


EM-2 Close-Out Welds at MAF



EM-2 Pressure Vessel in Welding Tool

Space Launch System (SLS) Status



EM-1 ICPS/OSA/LVSA (Marshall Space Flight Center/ULA-Decatur)

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- ✓ Interim Cryogenic Propulsion Stage (ICPS) ship to United Launch Alliance at Cape Canaveral Air Force Station for final outfitting
- ✓ ICPS Delivery to KSC - July 2017 (store in Space Station Processing Facility (SSPF))
- ✓ ICPS Hardware Acceptance Review - Oct 2017
- ✓ Orion Stage Adapter (OSA) Production Complete - January 2018
- ✓ OSA Delivery to KSC – April 2018 (store in SSPF)
- ✓ Launch Vehicle Stage Adapter (LVSA) Thermal Protection System (TPS) application complete - April 2018
- LVSA Production Complete - September 2018
- LVSA Delivery to KSC - October 2018



Thermal Insulation Application Complete on LVSA



ICPS
Start
Production



LVSA
Start
Production



ICPS
Flight Unit
Complete



OSA
Flight Unit
Complete

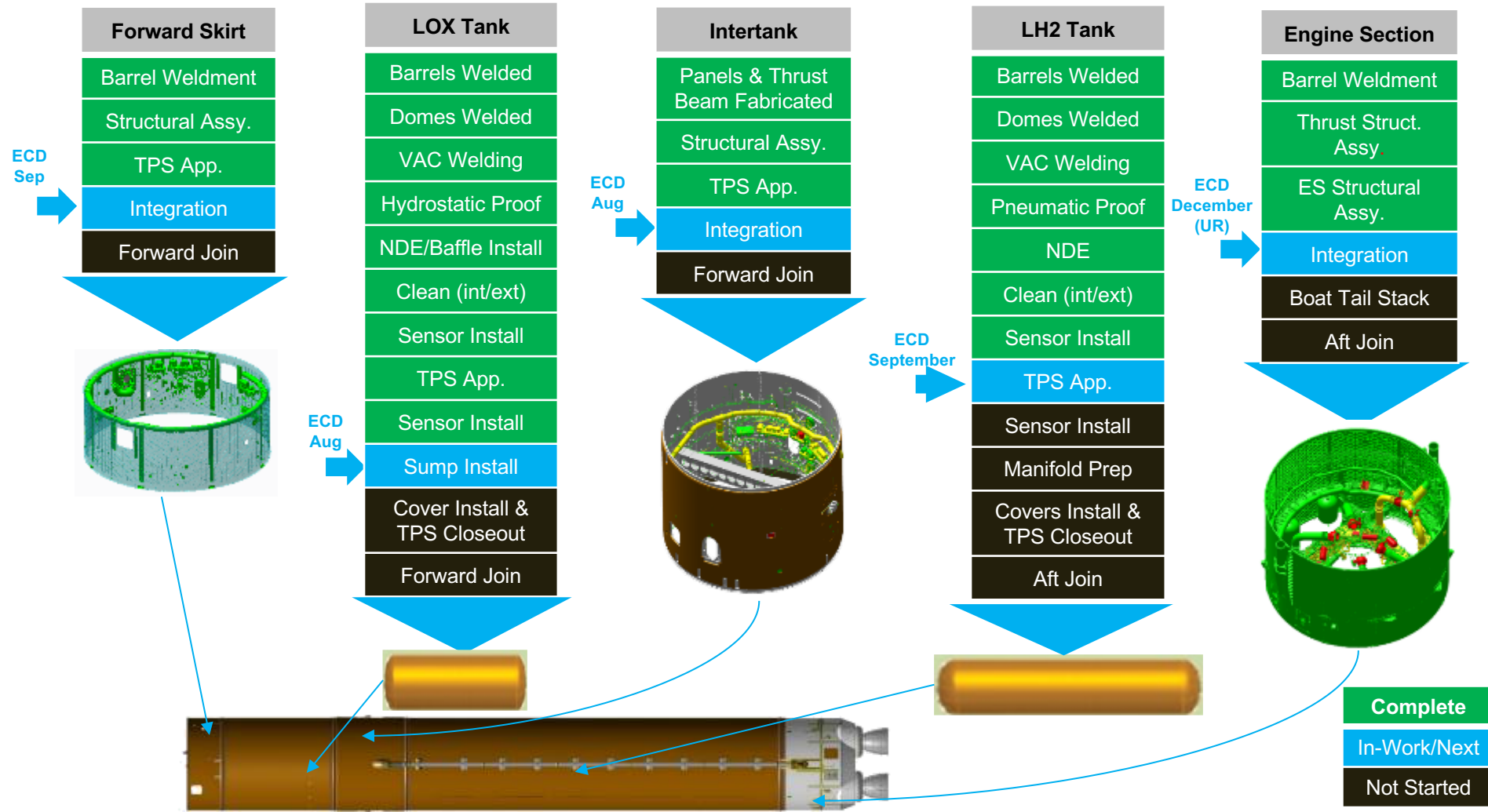


LVSA
Flight Unit
Complete



Delivery
KSC

EM-1 Stages (Boeing - MAF)

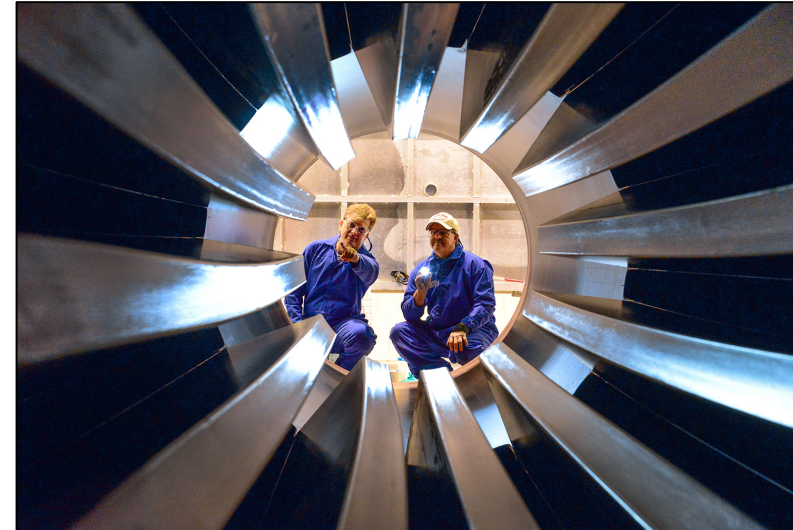


EM-1 Boosters (Northrop Grumman - Utah)

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- ✓ All Booster Separation Motors are cast and finalized
- ✓ EM-1 Left & Right Hand Booster Production progressing
- ✓ All EM-1 Segment Casting complete
- ✓ Both Aft skirts structural refurbishment complete
- ✓ Both EM-1 Nozzle assemblies and Aft Exit Cones complete
- ✓ Avionics Qualification Testing Complete
- ✓ EM-1 Left Hand aft skirt TVC lower frame installation complete
- ✓ 7 of 10 EM-1 Segments Finalized and in Storage
 - Propellant-liner-insulation (PLI) flight rationale complete - October 2018
 - EM-1 PLI Waiver signed – 1Q19
 - EM-1 Segments Ready to Ship - February 2019



Operators inspect propellant fins



Engineers remove the core after casting the booster case with propellant



QM-1
Test



QM-2
Test



EM-1
First Segment
Cast



EM-1 All
Segments
Cast



EM-1
Segments
Delivered

EM-1 Engines (Aerojet Rocketdyne – Stennis Space Center)

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- ✓ Held RS-25 Production Re-start Integrated Baseline Review (IBR) - May 2016
- ✓ Engine 0528 RS-25 (LOX Pump Pressure) Complete - Feb 2017
- ✓ Engine Control Unit (ECU) Flight Model (FM) -1 to 3 ATP Complete - Apr 2017
- ✓ Engine 0528 ECU Green Run Testing Complete
- ✓ EM-1 RS-25 Engines Deliver in Place - Oct 2017
 - *The EM-1 Flight Engines are Engine 2045, Engine 2056, Engine 2058, and Engine 2060*
 - RS-25 Development Test Campaign (First HIP bonded Main Combustion Chamber and controller Green Runs) - Aug 2018 through Jan 2019
 - EM-2 (EM-1 contingency engines) Engine Complete
 - E2059 - Nov 2018
 - E2047 - Dec 2018
 - E2063 - Jun 2019
 - E2059 - Aug 2019



Final Engine Adaptation / Software Cert Hot-fire Test



All 4 EM-1 Engines Delivered-in-place



ECU
Dev
Testing



ECU FM1 ATP
Complete



ECU Green Run
Testing Begins



EM-1 Green
Run Testing
Complete



EM-1 RS-25 Engines
Delivered to MAF

Software Test Lab (Marshall Space Flight Center)

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Software

- ✓ Deliver Flight Software Release 13 - December 2016
- ✓ Complete Sprint 5 Flight Software Release 14 - March 2017
- ✓ Complete Sprint 6 (final sprint) Flight Software Release 14 - May 2017
- ✓ Complete Release 14 Green Run Application Software (GRAS) - June 2018
- Release GRAS for Regression Testing – January 2019
- Complete Release 14 Flight Control Application Software (FCAS) - April 2019

✓ FSW 11
Release
(Engineering)

✓ FSW 12
Release
(Engineering)

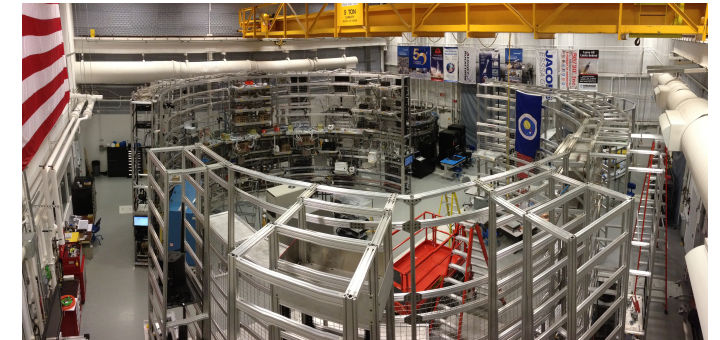
✓ FSW 13
Release

✓ FSW 14
Release
(GRAS)

□ FSW 14
Release
(FCAS)

Software Integration Test Facility (SITF) - Qualification Testing

- ✓ Complete Phase 1 (Pwr Quality & Verif) - May 2016
- ✓ Complete Phase 2 (Command and Data Handling (C&DH) & Flight Safety System (FSS) Dry Run) - October 2016
- ✓ Complete Phase 3 (Flt Ctrl & Telemetry (TLM) Dry Run) - June 2017
- Complete Phase 4 (Final Avionics Verif) - January 2019



SITF Qualification Testing

✓ SITF
Development

✓ SITF
Qual Test
Ph 1 Comp

✓ SITF
Qual Test –
Ph 2 Comp

✓ SITF
Qual Test –
Ph 3 Comp

□ SITF
Qual Test
Complete

EM-2 SLS Progress



EM-2 forward and center-forward booster segments



EUS RL-10 Engine P7001 Injector LO2 Plate



EM-2 Core Stage Engine Section Complete

Exploration Ground Systems Status



Umbilical LETF Testing/Mobile Launcher (KSC Launch Equipment Testing Facility)

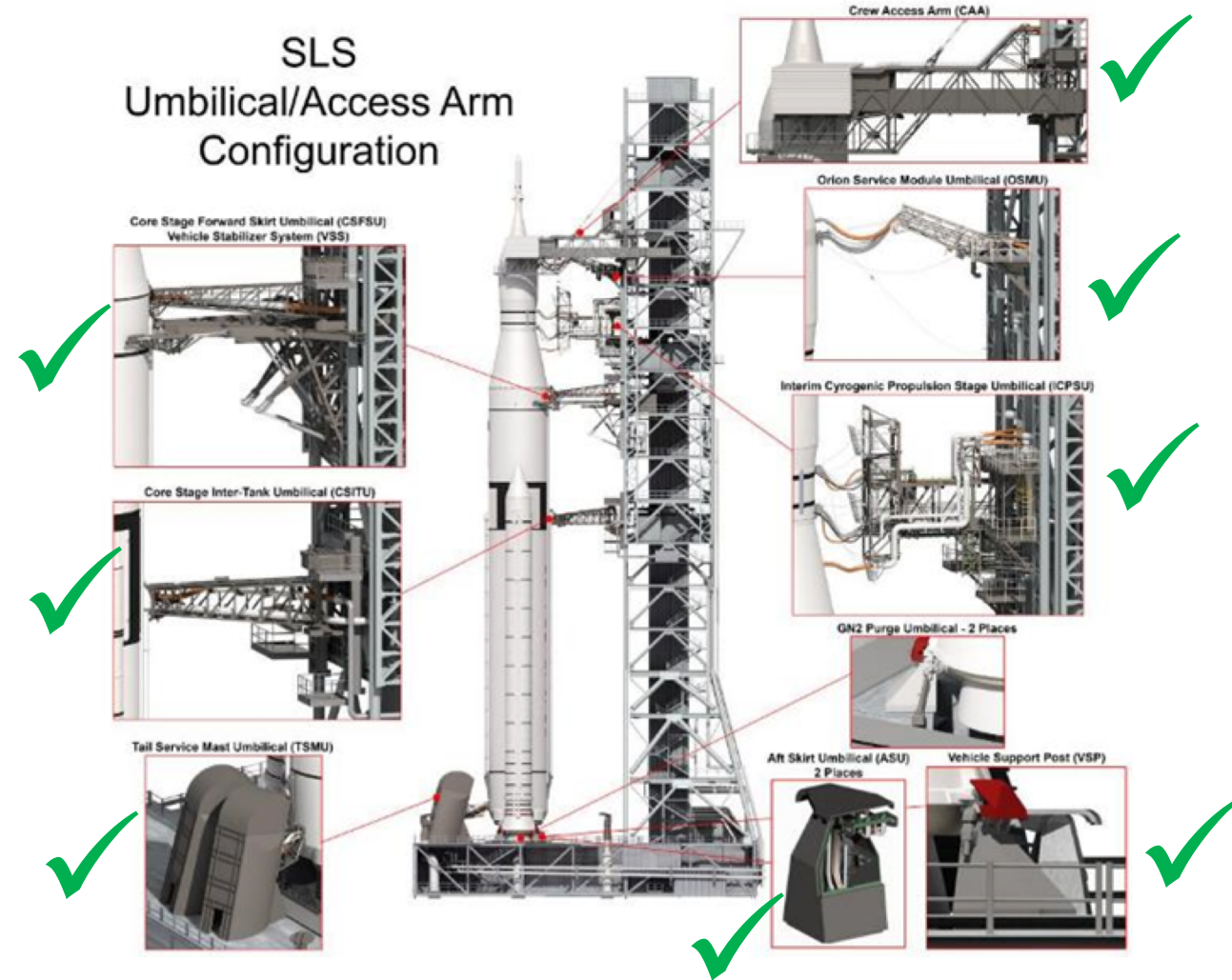
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- ✓ Interim Cryogenic Propulsion Stage Umbilical (ICPSU) installed – March 2018
- ✓ Crew Access Arm (CAA) installed – February 2018
- ✓ LO2 TSMU installed – July 2018
- ✓ LH2 TSMU installed – July 2018
- Parksite V&V – August 2018
- ML Fit check at Pad – September 2018
- ML Roll to VAB – September 2018
- ML/Pad Multi-Element V&V complete – 2019 Q3 (TBR)

EM-2 Development

- ✓ SRR for Facility subsystems completed – July 2018
- Concept study to finalize equipment layout for new & areas impacted by EES is in work



Crew Access Arm (CAA) Installed



Interim Cryo Propulsion Stage Umbilical (ICPSU)



LO2 Tail Service Mast Umbilical (TSMU)



LH2 TSMU



ML Fit Check at Pad



ML Roll to VAB



ML/Pad multi element V&V

Vehicle Assembly Building (KSC)

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EM-1 Progress

- ✓ All vehicle access platforms have been installed and outfitting is complete
- ✓ VAB High Bay (HB) 3 elevators are complete
- ✓ GSE Handling and Access (H&A) fabrication and installation is complete
- ✓ Fire Alarm/Firex System Acceptance Testing is complete
(During Firex wet flow testing, the measured flow rates did not meet required values in two out of four zones; Follow on work to replace legacy valves (85% complete) and sprinklers to meet new pump pressure and continue mock-up testing with new nozzles)
- Testing on the Environmental Control System (ECS) complete – September 2018

EM-2 Development

- VAB ECS and HB 3/4 design continue to mature
 - ✓ ECS 90% design review completed – July 2018
 - ✓ HB 3/4 60% design review completed – August 2018



CT-2 coming into HB-3



CT-2 parked inside HB-3



All Platforms
Installed



Platform Outfitting
Complete



Handling and
Access install



Fire Protection
Systems Complete



ME V&V

Pad 39B (KSC)

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EM-1 Progress

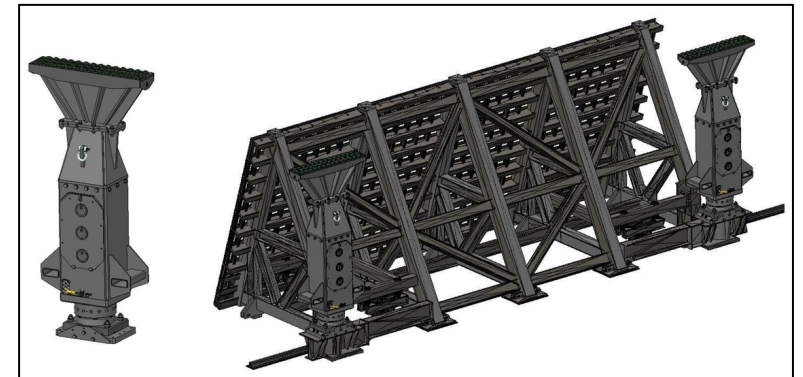
- ✓ Overall Pad B development is nearing completion
- ✓ Ignition Over Pressure and Sound Suppression (IOPSS) Wet Flow Testing complete – December 2017
- ✓ LH2 Storage Tank Fill complete – May 2018
- ✓ Pad Standalone Cryogenic Testing complete – May 2018
- ✓ LO2 Storage Tank Fill complete – July 2018
- ✓ Environmental Control System (ECS) refurbishment complete – April 2018
- ✓ ECS SW Field Testing Complete – August 2018
- Flame Trench/Flame Deflector is 96% complete

EM-2 Development

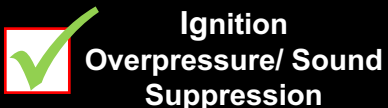
- ✓ Emergency Egress System (EES) Concept study extension to evaluate ML-1 and ML-2 interchangeability complete
- LH2 Upgrade Construction Award anticipated – August 2018
- Converter Compressor Facility (CCF) Design complete, construction planned to start in FY19



Flame Deflector



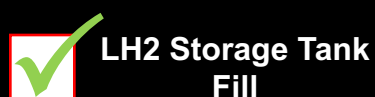
Flame Deflector with Extensible Columns



Ignition
Overpressure/ Sound
Suppression



Chillers



LH2 Storage Tank
Fill



Deflector



Flame
Trench



ECS

Multi-Payload Processing Facility (MPPF) (KSC)

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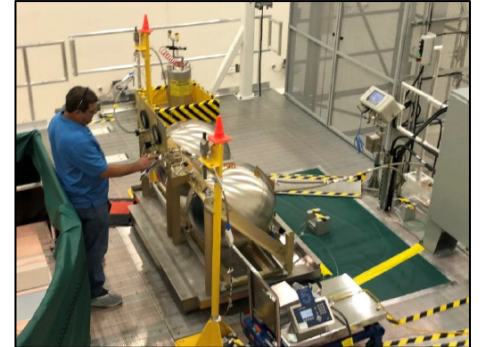
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MPPF standalone V&V activities

- ✓ Crew Module Ammonia Servicing Subsystem (CMASS), Gaseous Nitrogen (GN2), Gaseous Oxygen (GO2), Gaseous Helium (GHe), and Kennedy Complex Control System (KCCS) V&V activities are complete
- ✓ Orion Transportation Pallet (OTP) was received and V&V is complete
- ✓ Ground Cooling System V&V Test Readiness Review completed - February 2018

- Hypergol Servicing/Deservicing V&V testing being split for Fuel and Ox Testing
 - ✓ Cold Flow SCAPE demonstration occurred July 2018
 - Hot Flow start targeted for September 2018

- MPPF Ready to support Vehicle Processing – 2019 Q2 (TBR)



Crew Module Hypergol Cold Flow V&V Test Tanks



Hypers SCAPE demo at MPPF



V&V Start



CMASS Haz Testing



Orion Pallet Handling



Hypers Testing



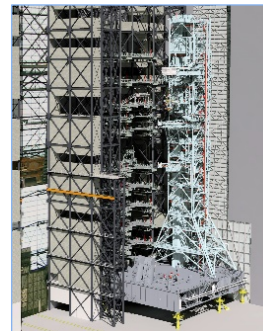
MPPF V&V Complete

Spaceport Command & Control System (SCCS)

- SCCS 4.0.1 - Hazardous Testing & GFAS Development/Test
- SCCS 5.0 – Orion Flight Vehicle Processing & GFAS V&V
- SCCS 6.0 – GFAS Regression, ITCO, WDR and EM-1 Launch



MPPF Hazardous Testing



MEVV @ VAB



MEVV @ Pad

- ✓ LCC Firing Room 2 Hardware Upgrades complete
- ✓ Integration Events (IE) 3 & 4, IE-4 included 500K cps complete
- SCCS 5.0 Engineering Release 2 – September 2018

SCCS 4.0 Validated Release

SCCS 4.0.1 System Test

SCCS 4.0.1 Validated

SCCS 5.0 Engineering Release

SCCS 5.0 Validated

SCCS 6.0 Engineering Release

SCCS 6.0 Validated

Ground Flight Application Software (GFAS)

GFAS in Firing Room 1 for Cryogenic Simulation



- HOTH test run for Avionics and COMM on FSW 28c platform completed – July 9-13
- Cross Program initiatives are increasing, yielding positive results (FSW integration, OMRS scripting & pre test, LCC / GLS algorithms, Greenrun / LCD)

GFAS Drop 10 & 11

GFAS (ECLSS/Hypers) V&V Complete

GFAS Ready for ML/Pad ME V&V

GFAS SC Offline Ready (SAR)

GFAS ITCO Ready (SAR)

