An Overview of Recent

Coordinated Human Exploration Studies

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Recent Exploration Mission Studies

Office of Exploration - 1988 Case Studies

- Human Expedition to Phobos
- Human Expedition to Mars
- Lunar Observatory
- Lunar Outpost to Early Mars Evolution

Office of Exploration - 1989 Case Studies

- Lunar Evolution
- Mars Evolution
- Mars Expedition

NASA 90-Day Study - 1989

- Reference Approach A - Moon as as testbed for Mars missions
- Reference Approach B - Moon as testbed for early Mars missions
- Reference Approach C - Moon as testbed for early Mars Outposts
- Reference Approach D - Relaxed mission dates
- Reference Approach E - Lunar tended outpost followed by Mars missions

America at the Threshold - "The Synthesis Group" - 1991

- Mars Exploration
- Science Emphasis for the Moon and Mars
- The Moon to Stay and Mars Exploration
- Space Resource Utilization

First Lunar Outpost - 1993

Early Lunar Resource Utilization - 1993

Human Lunar Return - 1996

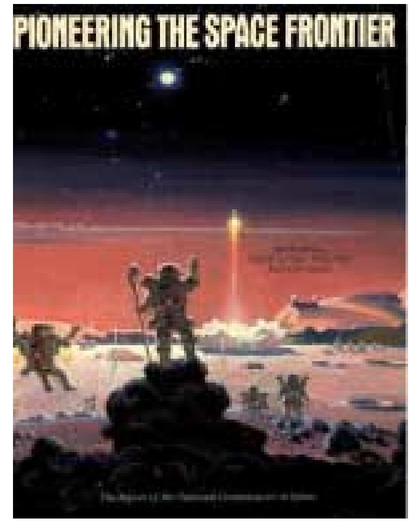
Mars Exploration Missions

- Design Reference Mission Version 1.0 - 1994
- Design Reference Mission Version 3.0 - 1997
- Design Reference Mission Version 4.0 - 1998
- Mars Combo Lander (JSC) - 1999
- Dual Landers - 1999

National Commission on Space
Pioneering the Space Frontier

Charter

- ***Appointed by the President, and charged by Congress, to formulate a bold agenda to carry America's civilian space enterprise into the 21st century***



May 1986

Program Thrusts

- ***Advancing our understanding of our planet, our Solar System, and the Universe***
- ***Exploring, prospecting, and settling the Solar System***
- ***Stimulating space enterprises for the direct benefit of the people on Earth***
- ***Advancing technology across a broad spectrum***
- ***Providing low-cost access to the space frontier***

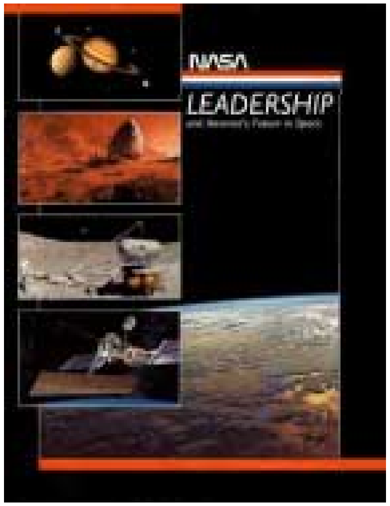
Principal Results

- Commission addressed all levels of human endeavor from expedition, to outposts, to Mars biospheres, to human settlement
- Recognized that *"world leadership in space will not be cheap, and that a reasonable fraction of national resources will be needed to maintain United States preeminence."*
- Recommended a "live off of the land" approach, utilizing local planetary resources to aid further exploration activities - *"the umbilical to Earth must be severed, or at least severely nicked"*

NASA's
Leadership and America's Future in Space

Charter

- Administrator Fletcher formed a task group in response to growing concern over the posture and long-term direction of the U.S. civilian space program
- Task force to:
  - Define potential U.S. space initiatives
  - Evaluate the initiatives in light of the current space program and nation's desires



August 1987

Four Candidate Initiatives

- Mission to Planet Earth
- Exploration of the Solar System (robotic)
- ***Outpost on the Moon (2000)***
- ***Humans to Mars (2005)***

Principal Results

- Task force recognized the potential benefits of using local resources to enhance exploration activities (In-Situ Resource Utilization)
- Recommended an evolutionary approach of expanding human presence into the solar system - "*tame and harness the space frontier*"
- Recognized the need to utilize the Space Station as a platform for life sciences research and recommended an aggressive approach
- Recommended an approach to design and prepare for a decision (2010) to an outpost on Mars
- *"We must pursue a more deliberate program . . . avoid a 'race to Mars'"*
- Recommended the establishment of an Office of Exploration within NASA

Office of Exploration 1988 & 1989 Case Studies

- Agency-wide analysis of exploration options
- Responds to the Office of Exploration objective of developing options and recommendations for a focused program for human exploration of the solar system

Strategies

- Human Expeditions
  - » Establish the first human presence on another planet
- Science Outpost
  - » Establish major extraterrestrial science outpost
- Evolutionary Expansion
  - » Sustain a step-by-step program to open the inner solar system for exploration, space science research, in-situ resource utilization, and permanent human presence

Studies Approach

- Case Studies
  - » End-to-end approaches for achieving various national exploration goals
- Broad Trades
  - » Aimed at addressing broad exploration related technical topics (on-orbit assembly, propulsion options, etc.)
- Special Assessments
  - » Focus on specific technologies

Human Expedition to Phobos

Objective

- Establishment of early leadership in human exploration of the solar system

Key Features

- All-chemical propulsion
- Split/sprint mission profile
- Direct earth entry
- Telerobotic exploration of Mars from Phobos
- 440-day round trip (30 days in Mars orbit)

Launch:	8/15/2002
Mars Arrival:	5/28/2003
Mars Departure:	6/27/2003
Earth Return:	10/29/2003

Principal Results

- All-chemical propulsion requires significant initial mass in low-earth orbit (~1800 t)
- Advanced propulsion technologies (aerocapture and nuclear thermal rocket) can significantly reduce mass requirements (57-72%)
- On-orbit assembly, storage of cryogenic propellants, and vehicle checkout increase mission complexity
- Development and incorporation of zero-g countermeasures in time to support the 2002 crew launch was challenging
- Large mass in LEO requires a heavy-lift launch capability and potentially on-orbit assembly capability

Human Expedition to Mars

Objective

- Establishment of early leadership in human exploration of the solar system

Key Features

- 3 human expeditions to Mars
- Chemical / aerobrake propulsion
- Split / sprint mission profile
- Aerocapture at earth return
- Vehicle assembly in low-earth orbit (SSF)
- 8 crewmembers per expedition (2006, 2009, 2011)
- 440-500 day round trip (20 days on Mars surface)

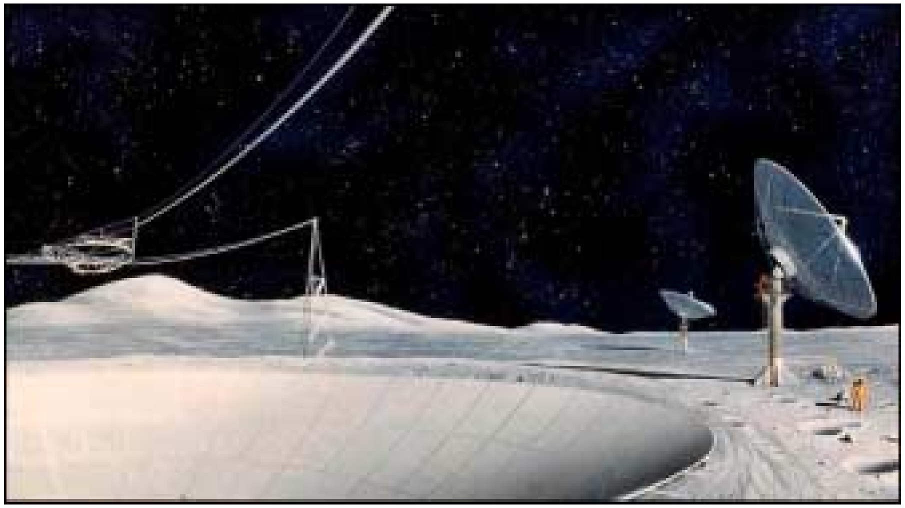
Principal Results

- Short-stay missions are energy intensive, thus requiring large transfer vehicles
- Advanced propulsion technologies (aerocapture and nuclear thermal rocket) can significantly reduce mass requirement (57-72%)
- On-orbit assembly, storage of cryogenic propellants, and vehicle checkout increase mission complexity
- Large mass in LEO requires a heavy-lift launch capability and potentially on-orbit assembly capability

Lunar Observatory

Objective

- Long-term acquisition of lunar surface, lunar environment, astrophysics, and astronomy data to advance our knowledge of the solar system.



Key Features

- Emplacement of a lunar observatory
- High robotic/human interaction
- Split cargo/human mission approach (1 piloted mission per year-14 day missions)
- Chemical/aerobrake propulsion
- Round trip missions to and from LEO
- First missions begin in 2004

Principal Results

- Considerable saving in both mass and cost could be achieved by utilizing reusable transportation vehicles
- Nuclear surface power system provide better energy density as compared to solar systems
- Extending surface stay-time decreases the number of required human missions
- Advanced Extra Vehicular Activity systems are required for extended lunar missions (mobility, dust)
- On-orbit assembly, storage of cryogenic propellants, and vehicle checkout increase mission complexity

Lunar Outpost to Early Mars Evolution

Objective

- Development of a sustained human presence beyond LEO (Moon and Mars)

Key Features

- Early emplacement of outposts on the moon and Mars which evolve to self-sustaining bases
- Extensive use of local resources (In-Situ Resource Utilization)
- Advanced technologies utilized (ISRU, electric propulsion, nuclear surface power)
- Lunar missions begin 2002
- Human missions to Mars missions begin 2010

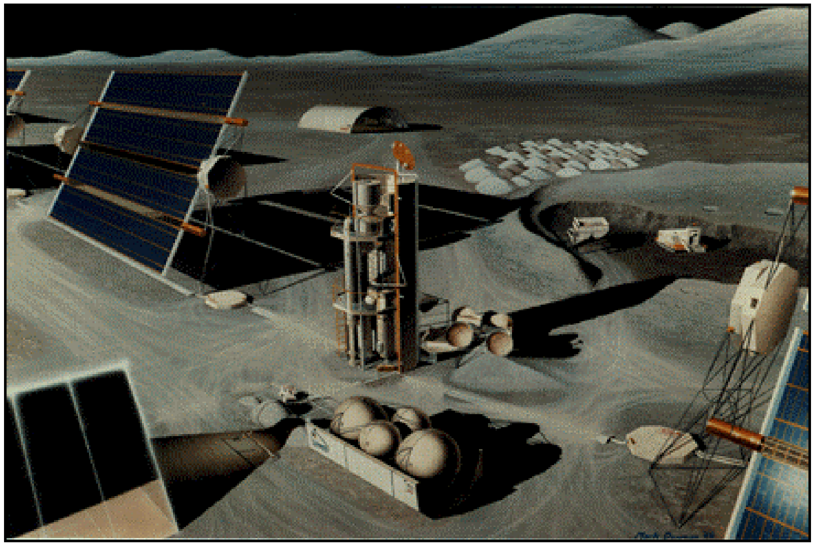
Principal Results

- Reliance on the large number of high technology elements imposes significant program risk
- Development of nuclear electric propulsion by 2007 (first Mars cargo flight) much too aggressive
- ISRU including propellant production and storage provide large mission leverage
- Human performance for long duration missions requires further analysis

Lunar Evolution

Objective

- Establish a permanent lunar outpost which supports significant science activities and serves as a stepping stone into the solar system



Key Features

- First human flight to the moon in 2004
- Reusable transportation vehicles
- Missions staged from SSF
- Crew size grows from 4 to 12
- Chemical/aerobrake propulsion
- Significant use of lunar resources (oxygen)

Principal Results

- Utilization of lunar oxygen provides great mass leverage (initial mass in LEO) and potential cost savings
- Large scale propellant production requires nuclear surface power (SP-100 derivatives utilized)
- Initial missions required complex on-orbit operations (rendezvous, docking, propellant transfer) with little operational experience in hand
- Propellant production capabilities requires enhanced surface mobility systems
- Operational experience gained at the lunar outpost is applicable to future exploration activities

Mars Evolution

Objective

- Emplace a permanent, largely self-sufficient outpost on the surface of Mars

Key Features

- First human flight in 2007 (4 growing to 7 crew)
- Vehicles assembled in LEO (free-flyer platform)
- Chemical / aerobraking propulsion
- Propellant production at Phobos
- Artificial-gravity spacecraft
- Surface stay initially 30-days growing to 500

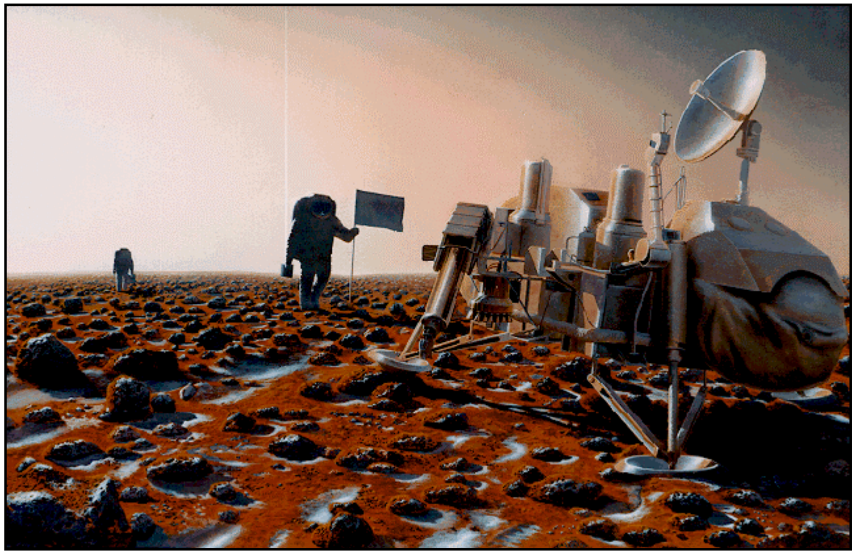
Principal Results

- Heavy-Lift launch vehicle (140 t to LEO) required to support mass and flight rate requirements
- Even with HLLV, extensive on-orbit assembly and check-out required in low-earth orbit
- Use of nuclear thermal rocket, in addition to aerobraking, would increase payload capability and reduce flight times to and from Mars
- Advanced EVA systems are required to support the extensive surface operations required
- Significant research and development of in-situ resource utilization processes are required
- Architecture requires delivery of approximately 500t to low earth orbit per year

Mars Expedition

Objective

- Embark upon the earliest possible human expedition to Mars



Key Features

- One mission to Mars
- All-up vehicle approach
- Chemical/aerobrake propulsion with direct earth entry
- Heavy lift launch vehicle (140t) with no on-orbit assembly
- 520-day round trip (20 days on Mars surface)

Launch:	6/10/2004
Mars Arrival:	4/11/2005
Mars Departure:	5/11/2005
Earth Return:	11/12/2005

Principal Results

- Imposing "Free Return" trajectory constraints significantly restricts the mission approach while exposing the crew to additional potential hazards
- Split/sprint approaches for short-stay expeditions is not beneficial (mass increased by 6%)
- Crew adaptation to partial-g environment during short (20 day) stay requires additional study

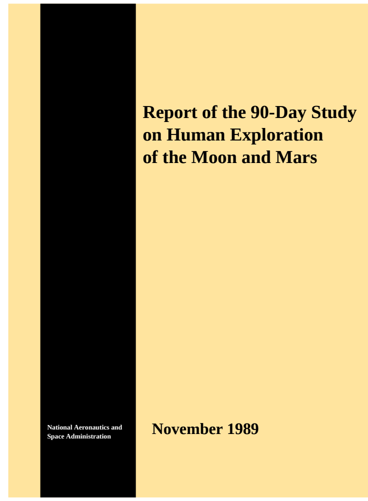
NASA 90-Day Study

Objective

- To provide a database for the National Space Council to refer to as it considered strategic planning issues
- Agency-wide study commissioned by Admiral Truly after the President's July 20, 1989 speech

Key Features

- Five reference approaches (generally similar)
- Robotic - Moon - Mars pathway
- Extensive use of:
  - Space Station Freedom for assembly and checkout operations
  - Reusable transportation vehicles (initially expendable)
  - In-Situ Resource Utilization (oxygen from the lunar regolith)
  - Chemical / aerobrake propulsion



November 1989

Key Trades

- Launch Vehicle Size
- In-space assembly or direct to the surface
- Freedom, new spaceport, or direct assembly
- Chemical, electric, nuclear, or unconventional
- Aerobraking or all-propulsive
- Expendable or reusable spacecraft
- Propellant or tank transfer
- Open or closed life support
- Zero-gravity or artificial-gravity Mars vehicle
- In situ or Earth-supplied resources

Principal Results

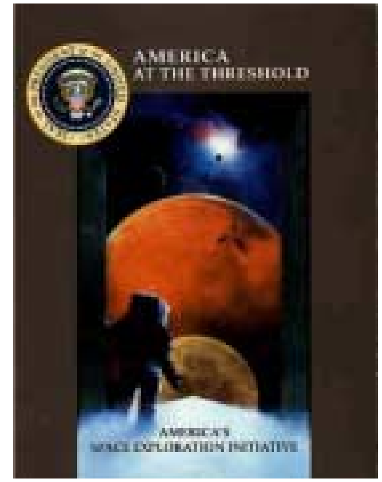
- Premature discussion / disclosure of cost results can have disastrous effects
- Use of local planetary resources can greatly enhance capabilities and reduce the cost of exploration
- Aerobraking reduces vehicle mass by as much as 50% as compared to all chemical systems
- Nuclear thermal propulsion provides a great deal of promise for Mars missions (40% mass reduction)

Charter

- Chartered by the National Space Council to develop several alternatives of exploration, future acquisition of scientific knowledge, and future space leadership.
- Chaired by Tom Stafford, Lieutenant General, U.S. Air Force (ret.)

Four Candidate Architectures

- Mars Exploration
- Science Emphasis for the Moon and Mars
- The Moon to Stay and Mars Exploration
- Space Resource Utilization



May 1991

Principal Results

- Several supporting technologies identified as key for future exploration:
  - Heavy Lift Launch Vehicle (150-250 mt)
  - Nuclear Thermal Propulsion
  - Nuclear electric surface power
  - Extravehicular activity suit
  - Cryogenic transfer and long-term storage
  - Automated rendezvous and docking
  - Zero-g countermeasures
  - Telerobotics
  - Radiation effects and shielding
  - Closed loop life support systems
  - Human factors for long duration space missions
  - Lightweight structural materials and fabrication
  - Nuclear electric propulsion for follow-on cargo deliv.
  - In situ resource evaluation and processing

Mars Exploration

Objective

- Explore Mars and provide significant science return

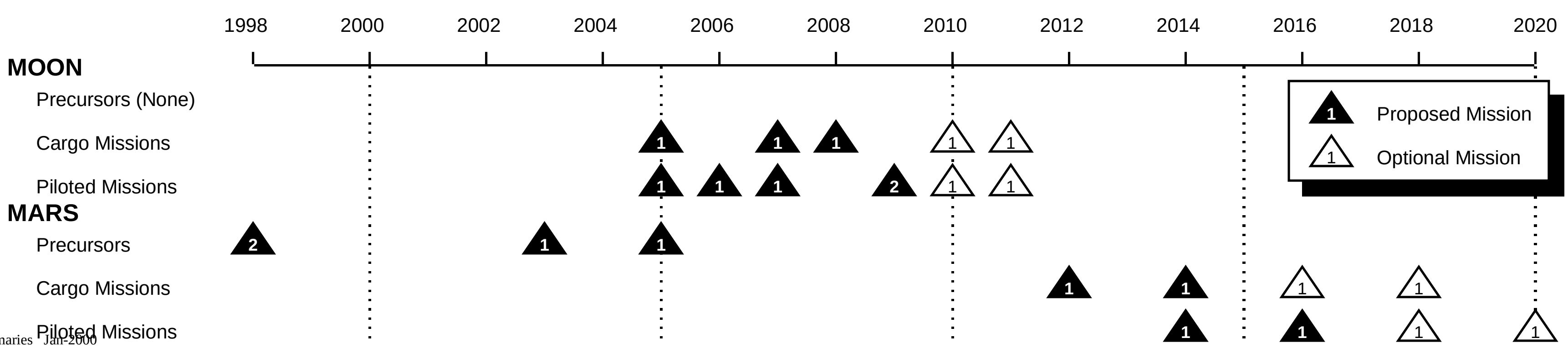
Key Features

- Minimal approach to achieve the program objectives
- Moon used as a testbed for Mars mission planning and system testing
- The moon is explored while developing operational concepts for Mars
- Mars mission dress rehearsal conducted on the moon in 2008-2009
- Two Mars missions planned:

  2014 (30-100 day surface stay)

  2016 (600 day surface stay)

  Options for additional missions in 2018 and 2020



Synthesis Group Architectures

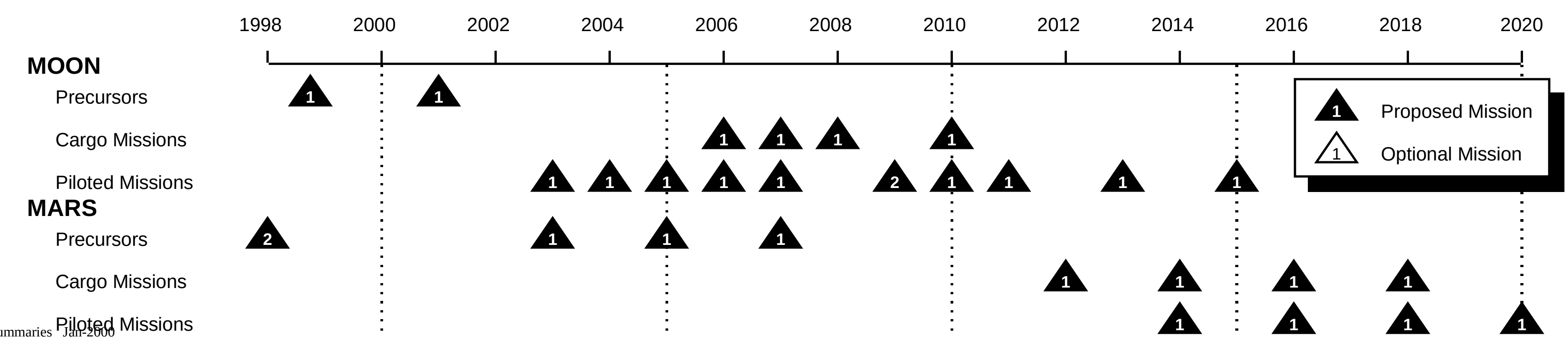
Science Emphasis for the Moon and Mars

Objective

- Balanced scientific return from both the moon and Mars.
- Emphasized throughout are exploration and scientific activities, including complementary human and robotic missions to ensure optimum return.

Key Features

- Global exploration is conducted in order to understand each planets global diversity
- The moon is used to gain needed life science data prior to Mars missions
- Teleoperation and telerobotics emphasized to assist human activity on the surface
- Near Earth Asteroid exploration option included
- Mars mission dress rehearsal conducted on the moon in 2008-2009
- Mars surface missions all long-stay (600 days on the surface)



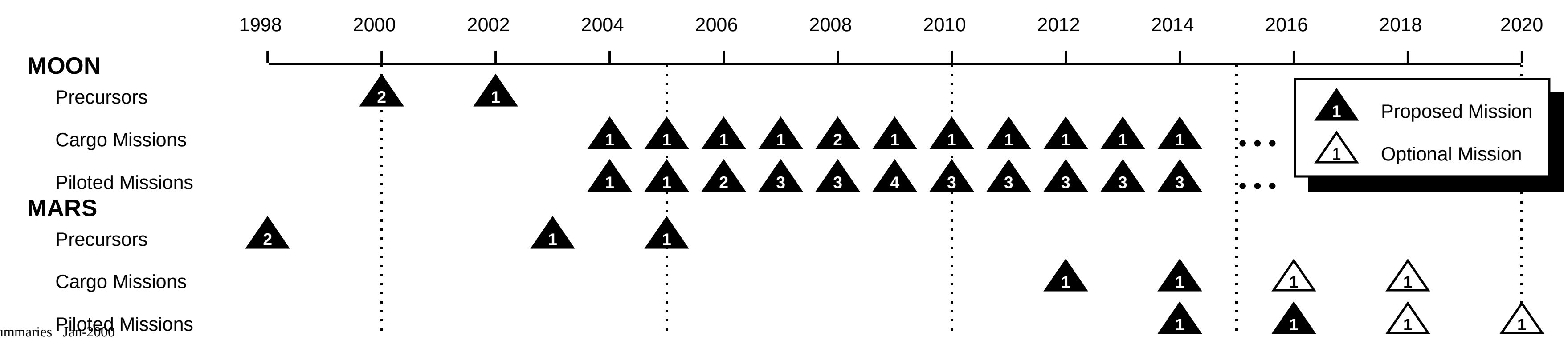
Moon to Stay and Mars Exploration

Objective

- Permanent human presence on the Moon combined with exploration of Mars

Key Features

- Emphasis placed on establishing independence from Earth
  - In situ resource utilization
  - Closed-loop life support systems
  - Food production
  - Reusable spacecraft
  - Large comfortable living and working spaces
- Lunar surface stay times gradually increase to permanent presence in 2007
- Mars mission dress rehearsal in 2009
- Lunar experience aids in Mars missions (600 day surface stays)



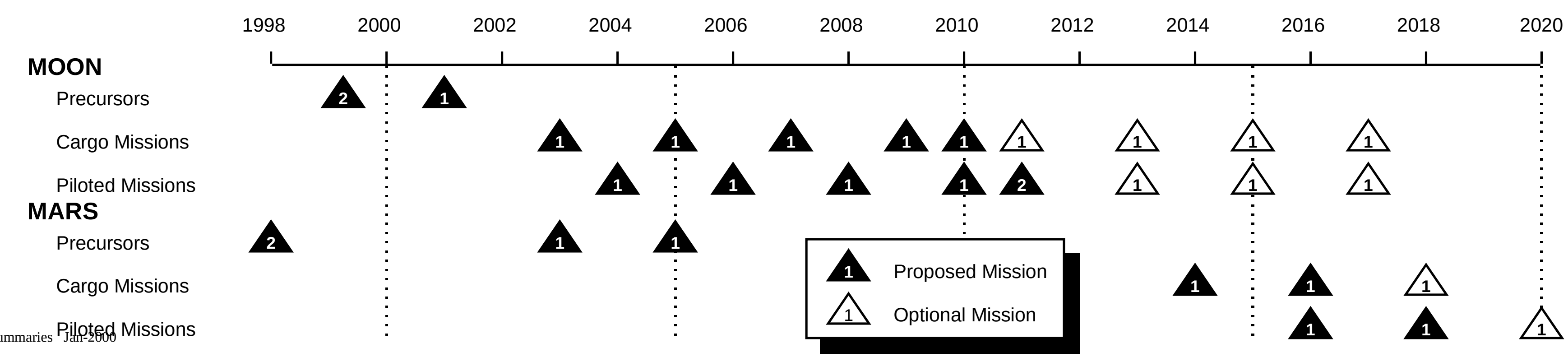
Space Resource Utilization

Objective

- Local planetary resources used to the maximum extent possible to aid exploration activities
- Seek to develop a large class of available resources for a broader range of transportation, habitation, life sciences, energy production, construction, and other long term activities.
- Goal is first to reduce the direct expense of going to the moon and Mars, then to build toward self-sufficiency, and eventually returning energy to Earth

Key Features

- Robotic demonstration of oxygen production prior to first lunar crew
- Oxygen use (power fuel cells) demonstrated by first lunar crew
- Capabilities of lunar systems rapidly enhanced to reduce resupply
- Includes demonstration of: lunar oxygen, Helium-3 extraction, beamed power, gas production, fuel , fused silica sheets, etc.
- Mars dress rehearsal conducted in 2011



First Lunar Outpost
"FLO"

Objective

- Internal NASA study aimed at understanding the technical, programmatic, schedule, and budgetary implications of restoring U.S. lunar exploration capability.
- Intended to be a benchmark against which compelling strategies could be measured

Approach

- Emphasized minimizing integration of elements and complex operations on the lunar surface
- High reliance on past and current programs in anticipation of lowering hardware development costs

Key Attributes:

- Heavy lift launch vehicle - direct descent to the lunar surface - direct return to earth
- Large pre-integrated systems designed for immediate occupancy by the crew
- Habitat pre-integrated with lander to avoid operations associated with off-loading

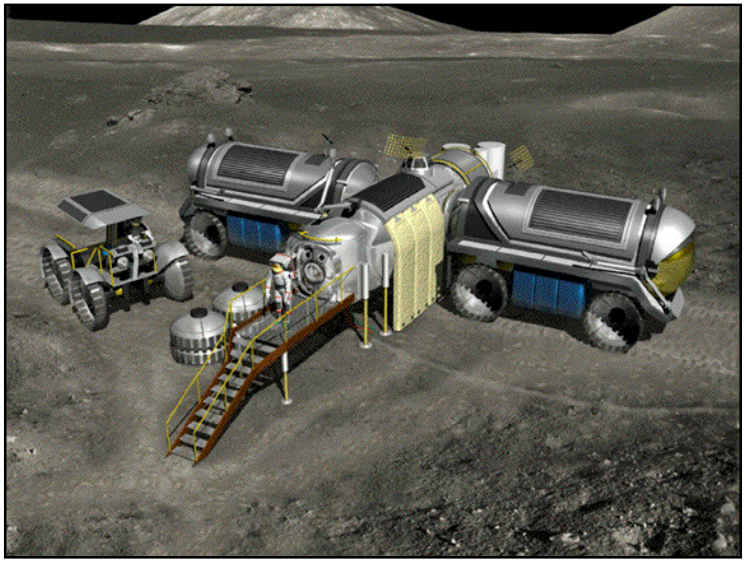
Principal Results

- Delivery requirements (large pre-integrated habitat) drives transportation system size
- Transportation systems comprise over half of the mission cost

Early Resource Utilization
"LUNOX"

Objective

- Internal NASA study aimed at reducing the development cost by utilizing lunar derived propellants from the initiation of the program



Approach

- Transportation vehicles designed to rely upon lunar-produced oxygen (LUNOX) for round-trip piloted missions from the beginning
- Oxygen production plant deployed and an initial cache of oxygen produced prior to first piloted flight
- Utilizing lunar oxygen reduces the size of all transportation elements, thus reducing development costs
- Surface systems pre-deployed via small cargo lander
- Shuttle derived launch vehicle adequate to meet delivery requirements

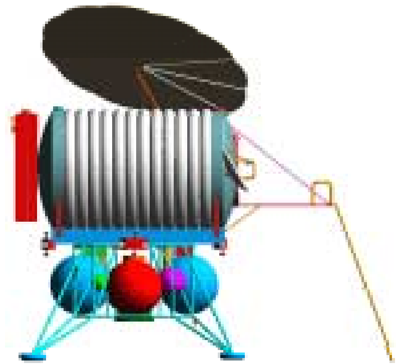
Principal Results

- Utilizing lunar produced propellants, from the onset of the program, can greatly reduce the cost of the missions:
    - Total mission cost reduce by 24%
    - Transportation costs reduced by 54%

Human Lunar Return

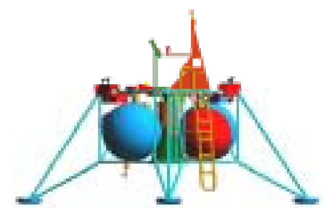
Objective

- Demonstrate and gain experience on the Moon with those technologies required for Mars exploration
- Near-term, low-cost strategy to initiate human exploration beyond Low Earth Orbit
- Establish and demonstrate technologies required for human development of lunar resources
- Investigate economic feasibility of commercial development and utilization of those resources



Approach

- Shuttle and Proton used for ETO transportation
- ISS houses mission elements prior to injection windows
- Pre-deployment of mission elements used to reduce mass
- Hybrid composites and inflatables for surface habitat supports two crew for up to six days
- "Open Cockpit" crew lander for two crew



Principal Results

- Mission set represents the minimum mission approach for a return to the Moon capability
- Lunar oxygen production is key to long term lunar access and technology is ready to demonstrate in the field
- It is possible to lower the cost of human lunar return to 5% of Apollo but no further due to the minimum size of humans, their life support needs, and required fault tolerance.

Mars Exploration Mission Studies
Design Reference Mission 1.0

1994

Objective

- Develop a "Reference Mission" based on previous studies and data.
- Reference Mission serves as a basis for comparing different approaches and criteria from future studies

Approach

- Limit the time that the crew is exposed to the harsh space environment by employing fast transits to and from Mars and abort to the surface strategy
- Utilize local resources to reduce mission mass
- Split Mission Strategy: Pre-deploy mission hardware to reduce mass and minimize risk to the crew
- Examine three human missions to Mars beginning in 2009
- Utilize advanced space propulsion (Nuclear Thermal Propulsion) for in-space transportation
- Payloads sent directly to Mars using a large launch vehicle (200+ mt to LEO)
- Nuclear surface power for robust continuous power

Principal Results

- Total mission mass approximately 900 mt for the first crew (3 cargo vehicles, 1 piloted vehicle)
- Development of the large launch vehicle is a long-lead and expensive system. Approaches using smaller launch vehicles should be investigated.

Mars Exploration Mission Studies
Design Reference Mission 3.0

1997

Objective

- Refine DRM 1.0 to improve identified weaknesses
- Provide further refinement of systems design and concepts

Approach

- Refine launch strategy to eliminate the need for the very large (200+ mt) launch vehicle. Dual launch (80 mt) strategy utilized.
- Repackage payload elements to reduce the physical size of the aerobrake used for Mars aerocapture and entry
- Investigate the need for the redundant surface habitat
- Incorporate emerging technologies and system concepts to reduce architectural mass

Principal Results

- Reduced system masses allowed for the elimination of redundant surface habitat, thus eliminating one Mars cargo vehicle
- Incorporation of TransHab concept in conjunction with other systems improvements (ECLSS, power, etc) resulted in a mass savings of ~30% at Mars entry.
- System mass improvements and revision of mission strategy resulted in over 50% payload mass savings
- Emerging systems concepts including Solar Electric Propulsion and Bi-Modal NTR shown to be viable alternative concepts
- Total mission mass estimates:
  - Nuclear Thermal Propulsion: 418 mt
  - Solar Electric Propulsion: 409 mt (early estimate)

Introduction and Background

- November 7, 1996 letter from the three AAs for the Space Science, and Human Exploration and Development of Space Enterprises chartered an integrated human / robotic Mars exploration study team.
  - There have been significant accomplishments including joint participation in near term Mars missions (2001, 2003)
- Subsequent direction from the AA for Space Flight suggested broadening the charter of this team to include additional destinations in the solar system.
- Team activities have also highlighted the importance of integrating contributions from the Office of Aeronautics and Space Transportation.

HRET Leadership- FY99

Steering Committee
(HQ Codes and Centers)

- I- Phillips Diaz
- M- Peach
- R- P. Sumrall
- S- Pilcher
- U- Ahlf

- ARC- Morrison
- GSFC- Kicza
- KSC- Morgan
- LaRC- Smith
- LeRC- Nieberding
- MSFC- Eoff
- SSC-Craig

Co-Chairs (Haynes, Cooke)

Integration
(Easter/Neubek)

***Mgt* & Customer Engagement**
(Easter/Mandell/ Craig)

Science
(McCleese/ Blanchard/ C. McKay)

Technology
(Rouff/Joosten)

Human Health and Performance
(Dastoor/Charles)

Missions
(Easter/Connolly/ Drake)

Human / Robotic Exploration Team Structure

Steering Committee
- •Policy/Budget Guidance
- •Agency advocacy
- •Oversight
- •Recommendations
- •Center Resources

Science
- •Science strategy
- •Science reqts

Co-Chairs (Haynes/Cooke)
- •Decision making
- • Advocacy

Robotic Exploration Team (Haynes)
- Science exploration strategy development-JPL (S)
- Overall robotic exploration integration-JPL
- Robotic science integration-JPL (Code S)
- Robotic mission execution-JPL
- Robotic msn technology dev-JPL
- Results collection & analysis-JPL, etc.

Human Exploration Team (Cooke)
- •Human exploration strategy dev-JSC
- •Overall human exploration integration-JSC
- •Transportation integration-MSFC
- •Life Science integration-JSC
- •Science integration-JSC, etc
- •Power integration-LeRC
- •Ops integration-JSC, KSC, MSFC

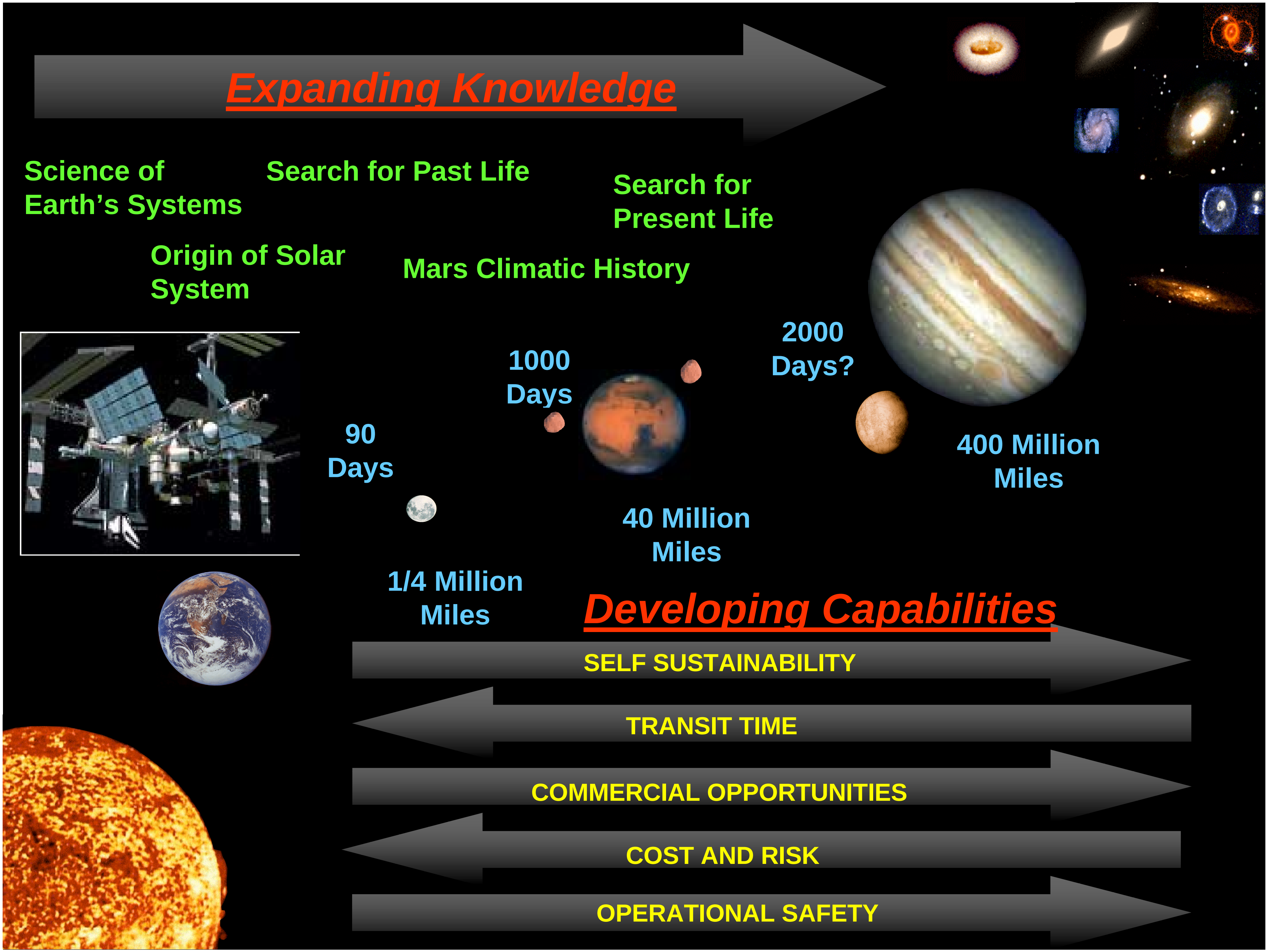
Integration
- •Overall programmatic SE&I-JPL/JSC
- •Overall admin integration- JPL/JSC

Mgt & Customer Engagement
- •NWODB
- •Outreach/Advocacy

Technology
- •Technology strategy
- •Technology reqts

Human Health & Performance
- •HH&P strategy
- •HH&P reqts

Missions
- •Mission strategy
- •Technical reqts


Expanding Knowledge
Science of Earth's Systems
Search for Past Life
Search for Present Life
Origin of Solar System
Mars Climatic History
90 Days
1000 Days
2000 Days?
1/4 Million Miles
40 Million Miles
400 Million Miles
Developing Capabilities
SELF SUSTAINABILITY
TRANSIT TIME
COMMERCIAL OPPORTUNITIES
COST AND RISK
OPERATIONAL SAFETY

Mars Exploration Mission Studies
Design Reference Mission 4.0

Exploration Office

Objective

- Refine DRM 3.0 to improve identified weaknesses
- Provide further refinement of systems design and concepts
- Improve risk abatement strategy

Approach

- Modify mission strategy to incorporate a round-trip crew transfer vehicle instead of pre-deploying the crew return habitat
- Place further emphasis on Solar Electric Propulsion concept (NTR and Chemical / Aerobrake investigated as options)
- Further refinement of In-situ resource utilization concept

1998

Principal Results

- Incorporation of a round-trip crew transfer vehicle reduces system reliability requirement from five to three years, but requires an additional rendezvous in Mars orbit
- End-to-end Solar Electric Propulsion vehicle mission concept is shown to be a viable concept, but vehicle packaging and size remain tall-poles
- Total mission mass estimates:
    - Solar Electric Propulsion: 467 mt
    - Nuclear Thermal Propulsion: 436 mt
    - Chemical / Aerobrake: 657 mt *

* similar but not same mission concept

Mars Exploration Mission Studies
Combo Lander

Exploration Office

Objective

- Focus on a single Mars crew lander which
  - Transports 6 crew from Mars orbit to the surface and back to orbit
  - Supports 6 crew for up to 500 days on the martian surface

1999

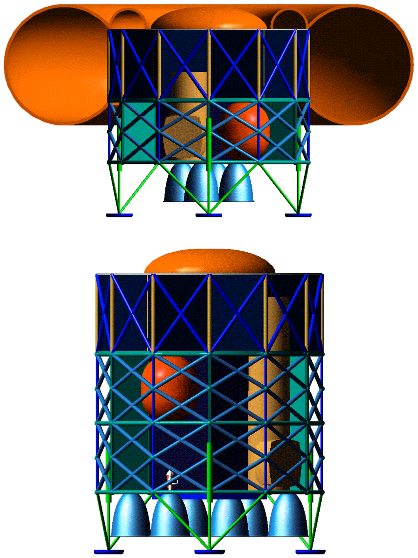
Approach

- Long-duration stay mission with fast transits to and from Mars
- Aerobraking at Mars
- Inflatable habitat for Mars surface vehicle
- ClF_5 / N_2H_4 and CH_4 / O_2 propellants investigated
- All propellants brought with the crew for abort-to-orbit scenarios
- Solar surface power

Principal Results

- Six 100-mt launches required to support mission scenario
- Several long-poles identified as potential show stoppers:
  - 100 mt launch system
  - Large (2.4 Mwe) Solar Electric Propulsion Vehicle
  - Deployment of drogue and main parachute at high speeds (M=4.5) required due to large vehicle mass
  - Surface system reusability not possible due to single vehicle design

Mars Exploration Mission Studies
Dual Landers



1999

Objective

- Refine Combo Lander approach to eliminate potential long-poles by separating the crew lander functions between two vehicles

Approach

- Long-duration stay mission with fast transits to and from Mars
- Aerobraking at Mars
- Descent / Ascent vehicle for crew transport from orbit, to surface, and back to Mars orbit
- Inflatable habitats for transit and surface vehicles
- CH_4 / O_2 propellants brought with the crew
- Solar surface power
- Solar Electric Propulsion used for interplanetary propulsion

Principal Results

- Six 100-mt launches required
- Significant improvement in aeroassist and parachute deployment conditions (as compared to Combo Lander II)
- Surface system reusability is enabled
- Greater improvement in Earth vicinity abort scenarios developed
- Total mission mass estimates:
  - Solar Electric Propulsion: 585 mt

Core Capabilities & Technologies

Exploration Office

Common Technology Building Blocks (Core Technologies)	***Common System Building Blocks (Core Capabilities)***	***Potential Destinations***

Examples

Efficient In-Space Prop..

Aeroassist

Low-cost Engines

Cryo Fluid Management

Robust/Efficient Power

Lightweight structures

Radiation Research

Zero/Low-g Research

Regenerable Life Support

Advanced Lightweight EVA

"Breakthrough"

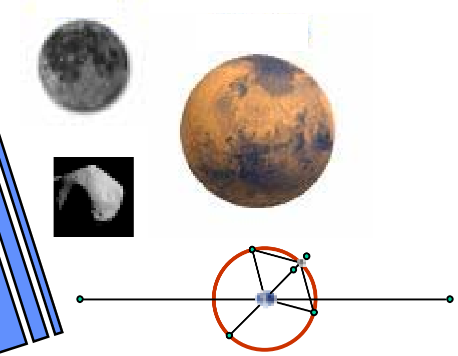
"Breakthrough"

"Breakthrough"

"Breakthrough" Technologies

System Design

Mission Analyses

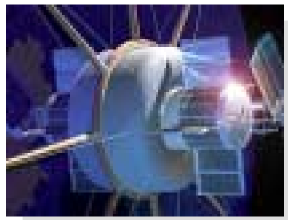


Human Exploration Common Capabilities

Earth to Orbit Transportation

Moon (follow on)
Asteroids
Mars

Interplanetary Habitation

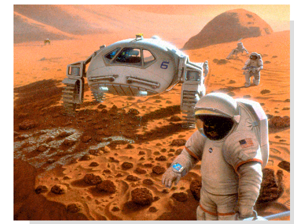


Moon
Sun-Earth Libration
Asteroids
Mars

Crew Taxi / Return

Moon
Sun-Earth Libration
Asteroids
Mars

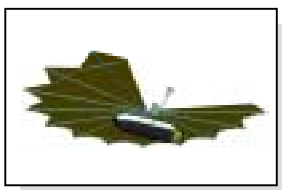
EVA & Surface Mobility



Moon
Mars
Asteroids

Advanced Space Transportation Options

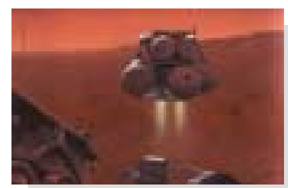
Advanced Chemical
"Small"
Moon (follow on)
Sun-Earth Libration
"Large"
Asteroids
Mars



Electric Propulsion
<500 kWe
Moon
Sun-Earth Libration
Mars Outpost
>1 MWe
Asteroids
Mars

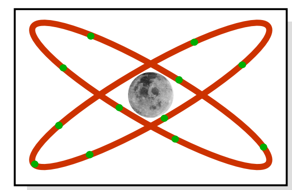
Nuclear Thermal
Asteroids
Mars
Moon (follow-on)

In-Situ Resource Utilization

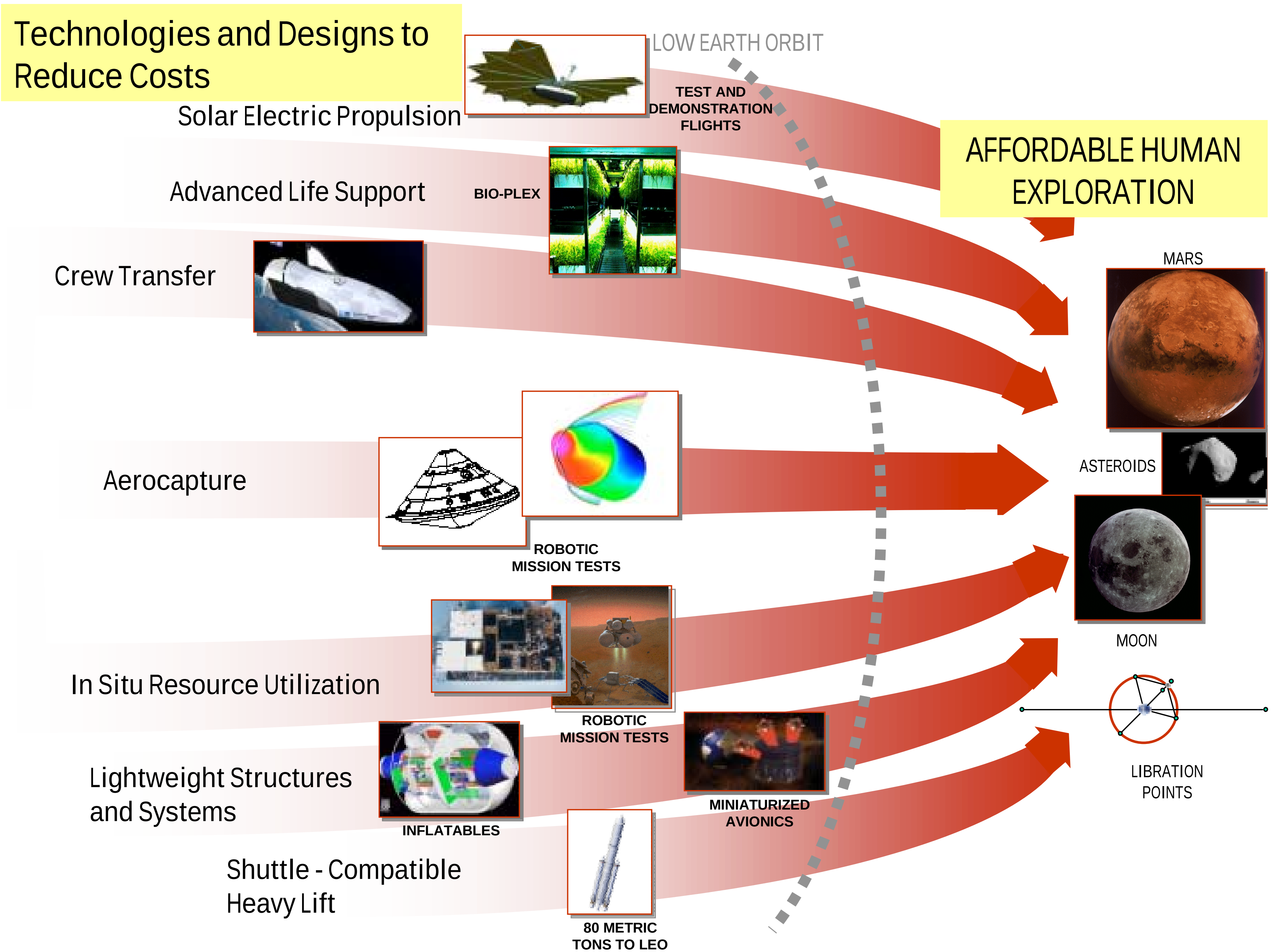


Moon
Mars

Com / Nav Infrastructure



Moon
Mars


Technologies and Designs to Reduce Costs
Solar Electric Propulsion
LOW EARTH ORBIT
TEST AND DEMONSTRATION FLIGHTS
AFFORDABLE HUMAN EXPLORATION
Advanced Life Support
BIO-PLEX
Crew Transfer
MARS
Aerocapture
ASTEROIDS
ROBOTIC MISSION TESTS
MOON
In Situ Resource Utilization
ROBOTIC MISSION TESTS
LIBRATION POINTS
Lightweight Structures and Systems
INFLATABLES
MINIATURIZED AVIONICS
Shuttle - Compatible Heavy Lift
80 METRIC TONS TO LEO