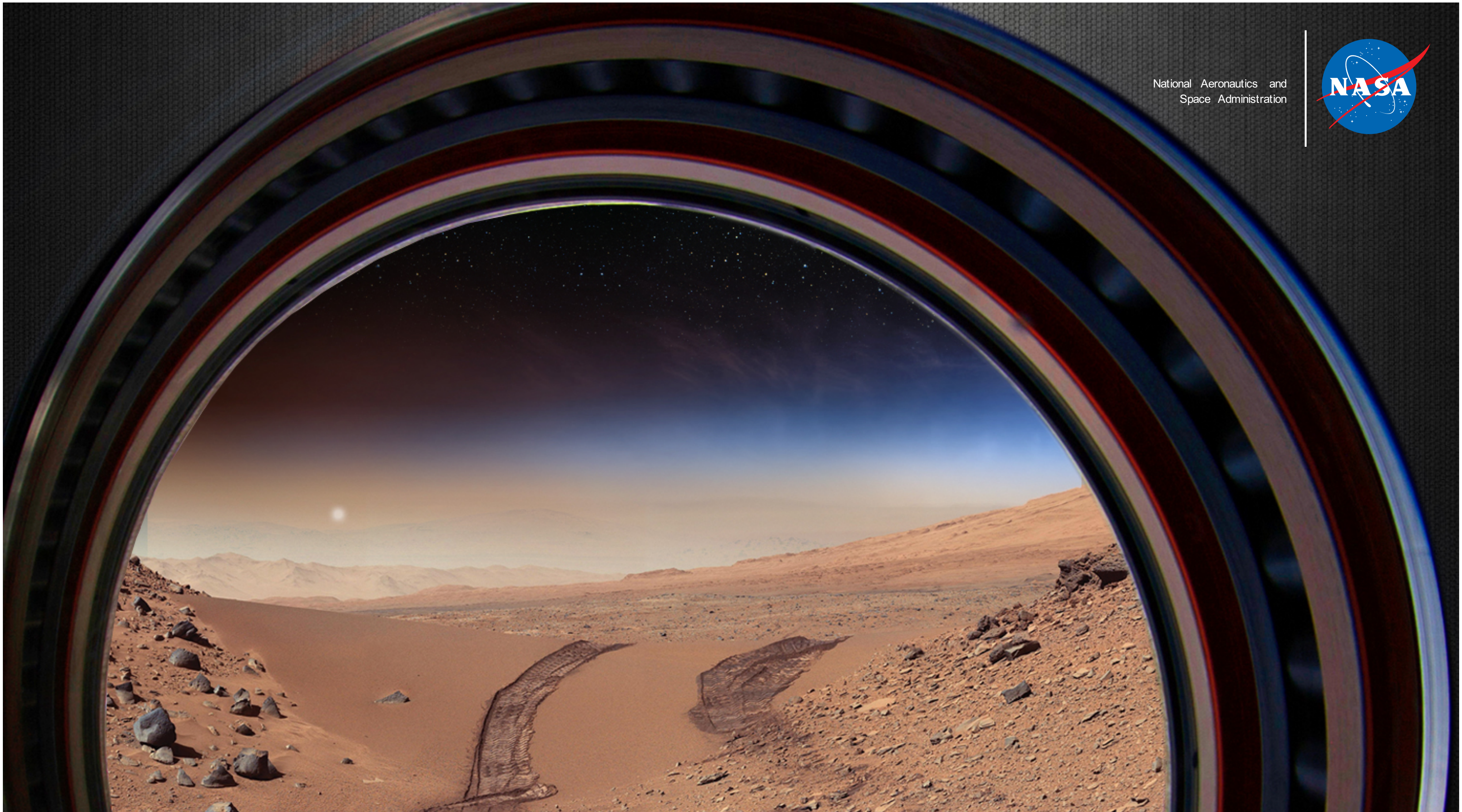


National Aeronautics and Space Administration

Human Exploration & Operations Progress and Plans on the Journey to Mars

William H. Gerstenmaier | April 26, 2016

Human Exploration and Operations

Budget Overview

- FY 2017 budget submit provides $8.4 billion ($8.2 billion discretionary and $0.2 billion mandatory) for Human Exploration and Operations (HEO) to pursue NASA goals, consistent with NASA Authorization Act of 2010
  - Sustain the capability for long duration presence in low Earth orbit (LEO)
  - Expand permanent human presence beyond LEO
  - Enable missions to deep space destinations such as cis-lunar space, near-Earth asteroids and Mars
  - Provide critical communication, navigation, launch, propulsion test, and other services to NASA, HEO missions, and other external customers
- Develops next generation launch vehicle, crew vehicle, and associated ground systems necessary to extend human presence beyond LEO (Orion, Space Launch System (SLS) and Exploration Ground Systems (EGS))
- Advances capabilities required to conduct a sustainable campaign of more complex exploration missions in cis-lunar space on the Journey to Mars
  - Research human health and performance so crew can travel safely beyond LEO
  - Develop and test technological capabilities needed for long duration missions (i.e. habitat system concepts)
  - Continues formulation of the Asteroid Redirect Robotic Mission (ARRM)

Human Exploration and Operations

Budget Overview (continued)

- Establishes a new theme in Space Operations, Space Transportation, which includes Crew and Cargo and Commercial Crew Programs
- Purchases reliable cargo resupply services from U.S. private sector companies
- Develops U.S. commercial crew capability to ISS by the end of 2017, ending sole reliance on Russia for U.S. crew access to space
- Utilizes International Space Station (ISS) as a research and technology test platform through at least 2024
  - Provide advanced human systems research and technology to enable safe, reliable, and productive human exploration beyond LEO required for Journey to Mars
  - Enable National Laboratory for commercial research and other government agencies
- Provides mission-critical enabling capabilities for HEO, other NASA, and other U.S. Government missions
  - Deliver space communications and navigation services necessary for success of NASA science and human missions and U.S. Government and commercial customer missions
  - Provide affordable and reliable launch access to space for NASA and civil sector missions
  - Continue crew training and operations, crew health and safety, and propulsion test activities required for successful U.S. crewed space missions

Human Exploration and Operations

Program Financial Plan

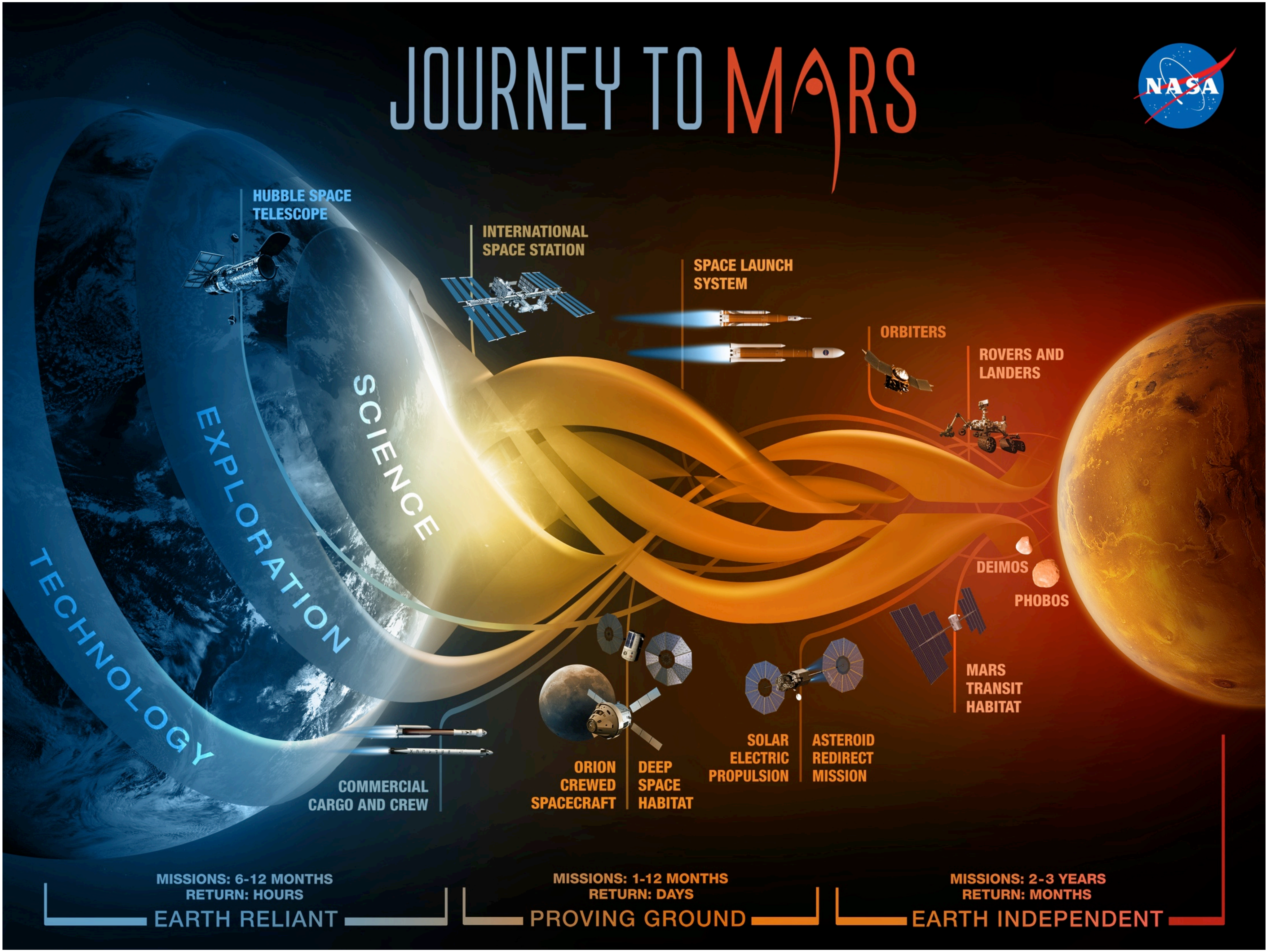
Budget Authority ($ in Millions)	Actual FY 2015	Enacted FY 2016	Request FY 2017	Notional FY 2018	FY 2019	FY 2020	FY 2021
Human Exploration and Operations	**8,168**	**9,059**	**8,413**	**8,443**	**8,611**	**8,784**	**8,959**
Exploration	**3,543**	**4,030**	**3,337**	**3,530**	**4,082**	**4,244**	**4,262**
Exploration Systems Development	**3,212**	**3,680**	**2,860**	**2,923**	**3,062**	**3,092**	**3,142**
Orion	1,190	1,270	1,120	1,120	1,124	1,135	1,153
Space Launch System	1,679	2,000	1,310	1,361	1,485	1,500	1,524
Exploration Ground Systems	343	410	429	441	453	458	465
Exploration Research and Development	**331**	**350**	**477**	**607**	**1,020**	**1,151**	**1,119**
Human Research Program	142	-	153	178	178	180	183
Advanced Exploration Systems	189	-	324	429	842	971	937
Asteroid Redirect Mission	*14*	*38*	*73*	*141*	*400*	*500*	*425*
Habitation	*54*	*55*	*90*	*112*	*150*	*200*	*275*
Space Operations	**4,626**	**5,029**	**5,076**	**4,913**	**4,530**	**4,540**	**4,698**
Space Shuttle Program	**8**	**-**	**-**	**-**	**-**	**-**	**-**
Space Shuttle Program	8	-	-	-	-	-	-
International Space Station	**1,525**	**-**	**1,431**	**1,555**	**1,537**	**1,539**	**1,585**
ISS Systems Operations and Maintenance	1,113	-	1,109	1,246	1,196	1,193	1,233
ISS Research	412	-	322	309	340	347	353
Space Transportation	**2,254**	**-**	**2,758**	**2,475**	**2,119**	**2,144**	**2,214**
Commercial Crew	805	-	1,185	732	173	36	36
Crew and Cargo	1,449	-	1,573	1,743	1,946	2,109	2,178
Space and Flight Support	**839**	**-**	**887**	**883**	**874**	**856**	**899**
21st Century Space Launch Complex	35	-	12	-	-	-	-
Space Communications and Navigation	579	-	612	616	598	576	615
Human Space Flight Operations	100	-	128	130	140	142	144
Launch Services	81	-	87	89	89	90	91
Rocket Propulsion Test	44	-	48	48	48	48	49
Construction and Environmental Compliance	**87**	**36**	**37**	**-**	**-**	**-**	**-**
Exploration	**68**	**10**	**9**	**-**	**-**	**-**	**-**
Space Launch System	21	5	6	-	-	-	-
Exploration Ground Systems	47	5	3	-	-	-	-
Space Operations	**19**	**26**	**29**	**-**	**-**	**-**	**-**
International Space Station	-	6	-	-	-	-	-
21st Century Space Launch Complex	5	3	3	-	-	-	-
Space Communications and Navigation	14	18	24	-	-	-	-
Launch Services	1	-	1	-	-	-	-

FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.

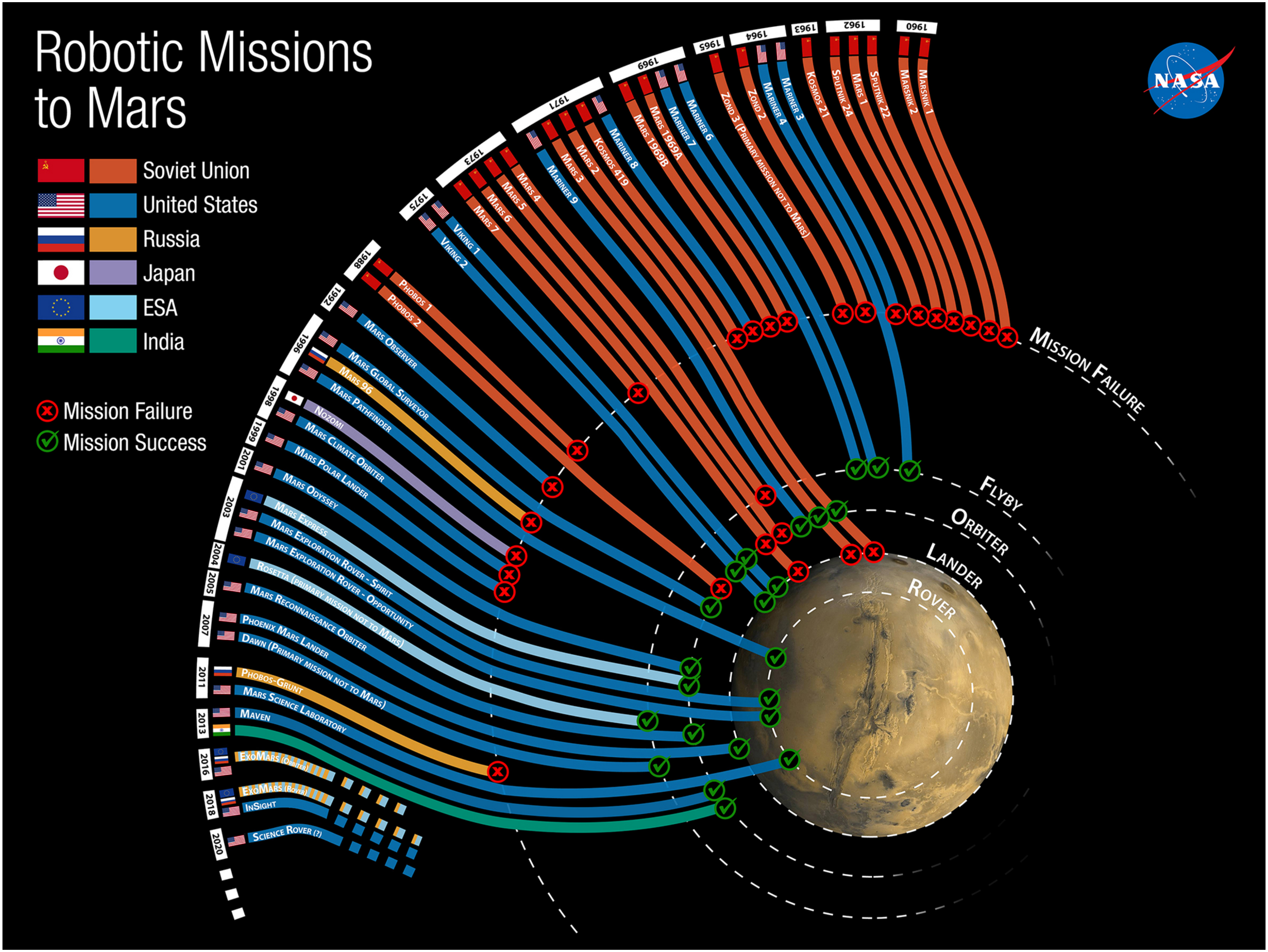
FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.

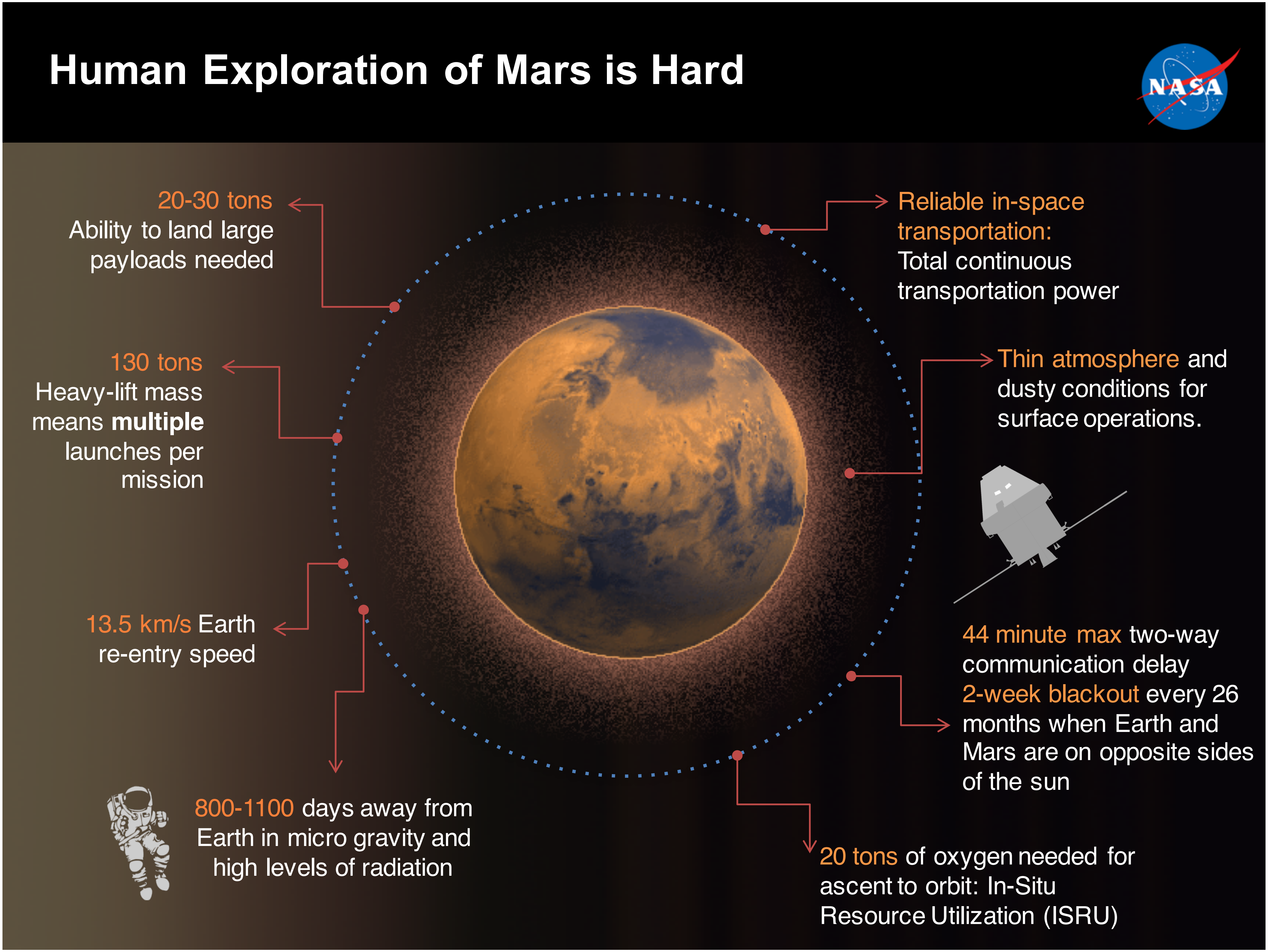
FY 2017 includes $173 million in mandatory funding (Orion $66.4, SLS $80.4 and EGS $26.2).

Totals may not add due to rounding



JOURNEY TO MARS
NASA
HUBBLE SPACE TELESCOPE
INTERNATIONAL SPACE STATION
SPACE LAUNCH SYSTEM
ORBITERS
ROVERS AND LANDERS
SCIENCE
EXPLORATION
TECHNOLOGY
DEIMOS
PHOBOS
MARS TRANSIT HABITAT
SOLAR ELECTRIC PROPULSION
ASTEROID REDIRECT MISSION
ORION CREWED SPACECRAFT
DEEP SPACE HABITAT
COMMERCIAL CARGO AND CREW
MISSIONS: 6-12 MONTHS
RETURN: HOURS
EARTH RELIANT
MISSIONS: 1-12 MONTHS
RETURN: DAYS
PROVING GROUND
MISSIONS: 2-3 YEARS
RETURN: MONTHS
EARTH INDEPENDENT


Robotic Missions to Mars
Soviet Union
United States
Russia
Japan
ESA
India
Mission Failure
Mission Success
NASA
1960
Marsnik 1
Marsnik 2
1962
Sputnik 22
Mars 1
Sputnik 24
1963
Kosmos 21
1964
Mariner 3
Mariner 4
Zond 2
1965
Zond 3 (primary mission not to Mars)
1969
Mariner 6
Mariner 7
Mars 1969A
Mars 1969B
1971
Mariner 8
Kosmos 419
Mars 2
Mars 3
Mariner 9
1973
Mars 4
Mars 5
Mars 6
Mars 7
1975
Viking 1
Viking 2
1988
Phobos 1
Phobos 2
1992
Mars Observer
1996
Mars Global Surveyor
Mars 96
Mars Pathfinder
1998
Nozomi
1999
Mars Climate Orbiter
Mars Polar Lander
2001
Mars Odyssey
2003
Mars Express
Mars Exploration Rover - Spirit
Mars Exploration Rover - Opportunity
2004
Rosetta (primary mission not to Mars)
2005
Mars Reconnaissance Orbiter
2007
Phoenix Mars Lander
Dawn (primary mission not to Mars)
2011
Phobos-Grunt
Mars Science Laboratory
2013
Maven
2016
ExoMars (Orbiter)
2018
ExoMars (Rover)
InSight
2020
Science Rover (?)
Mission Failure
Flyby
Orbiter
Lander
Rover


Human Exploration of Mars is Hard
NASA
20-30 tons
Ability to land large payloads needed
130 tons
Heavy-lift mass means **multiple** launches per mission
13.5 km/s Earth re-entry speed
800-1100 days away from Earth in micro gravity and high levels of radiation
Reliable in-space transportation:
Total continuous transportation power
Thin atmosphere and dusty conditions for surface operations.
44 minute max two-way communication delay
2-week blackout every 26 months when Earth and Mars are on opposite sides of the sun
20 tons of oxygen needed for ascent to orbit: In-Situ Resource Utilization (ISRU)

Mars is the Right Place for Human Exploration

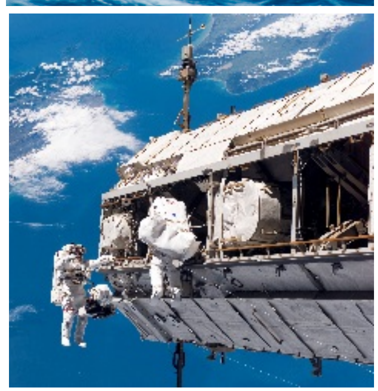
- **Robotic exploration has provided a very sound basis for a human mission**
- **Mars weather Temperature: -86 C to 20 C**
  - Tolerable for typical spacecraft systems
  - Varies with location
- **Water available for propellant and use of ascent vehicle**
- **CO_2 in atmosphere for O_2 extraction**
- **Radiation measured and tolerable**
  - Even thin atmosphere provides some protection
  - Varies through day/night
- **Mars geology is right for the advantages of direct human interaction and sampling**
- **Mars can tell us a lot about Earth and the possibility of life in the solar system**

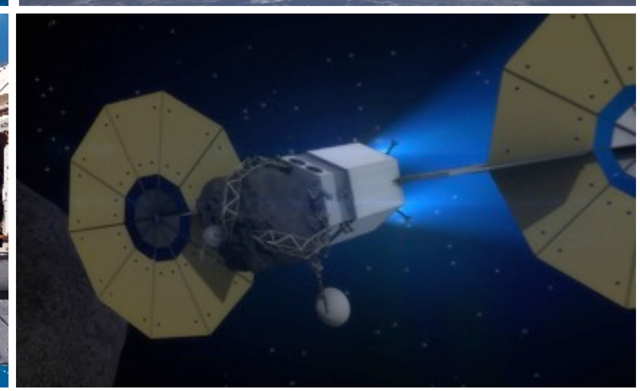
Humans to Mars: Achievable by Taking the Long View

- **Use the International Space Station (ISS) to retire / mitigate risks to human health and test deep space habitation technologies**
- **Develop multi-decadal transportation infrastructure that can support an affordable cadence and flexible launch and deployment capability**
- **Conduct the architecture studies and technology development needed to enable our next steps**
- **Engage international partners**
- **Facilitate commercial investment in and use of the space environment**

Human Exploration and Operations Mission Directorate (HEOMD) has more human space systems development ongoing today than at any time since Apollo!

Continuous human presence on ISS for 15 years





Strategic Principles for Sustainable Exploration

- **FISCAL REALISM: Implementable in the *near-term with the buying power of current budgets* and in the longer term with budgets commensurate with economic growth*;***
- **SCIENTIFIC EXPLORATION*: Exploration enables science and science enables exploration;* leveraging scientific expertise for human exploration of the solar system.**
- **TECHNOLOGY PULL AND PUSH: Application of high Technology Readiness Level (TRL) technologies for near term missions, while focusing sustained investments on *technologies and capabilities* to address the challenges of future missions;**
- **GRADUAL BUILD UP OF CAPABILITY: *Near-term mission opportunities* with a defined cadence of compelling and integrated human and robotic missions, providing for an incremental buildup of capabilities for more complex missions over time;**
- **ECONOMIC OPPORTUNITY: Opportunities for *U.S. commercial business* to further enhance their experience and business base;**
- **ARCHITECTURE OPENNESS AND RESILENCE: Resilient architecture featuring multi-use, evolvable space infrastructure, minimizing unique developments, with each mission leaving something behind to support subsequent missions;**
- **GLOBAL COLLABORATION AND LEADERSHIP: Substantial *new international and commercial partnerships,* leveraging current International Space Station partnerships and building new cooperative ventures for exploration; and**
- **CONTINUITY OF HUMAN SPACEFLIGHT*: Uninterrupted expansion of human presence into the solar system* by establishing a regular cadence of crewed missions to cislunar space during ISS lifetime.**

Human Space Exploration Phases From ISS to the Surface of Mars

Today

Phase 0: Exploration Systems ***Testing on ISS***

Ends with testing, research and demos complete*

Phase 1: ***Cislunar Flight Testing*** of Exploration Systems

Asteroid Redirect-Crewed Mission Marks Move from Phase 1 to Phase 2

Phase 2: ***Cislunar Validation*** of Exploration Capability

Ends with one year crewed Mars-class shakedown cruise

Phase 3: Crewed Missions Beyond Earth-Moon System

Phase 4a: Development and robotic preparatory missions

Phase 4b: Mars Human Landing Missions

▲ Planning for the details and specific objectives will be needed in ~2020

Mid-2020s

2030

* There are several other considerations for ISS end-of-life

Capability Development Risk Reduction

	Capability \ Mission	ISS	Cis-lunar Short Stay (e.g. ARM)	Cis-lunar Long Stay	Mars Robotic	Mars Orbit	Mars Surface
Working in Space and On Mars	In Situ Resource Utilization & Surface Power		Exploratory ISRU Regolith	Exploratory ISRU	Exploratory ISRU & Atmosphere	Exploratory ISRU	Operational ISRU & High Power
	Habitation & Mobility	Long Duration with Resupply	Initial Short Duration	Initial Long Duration		Resource Site Survey	Long Duration / Range
	Human/Robotic & Autonomous Ops	System Testing	Crew-tended	Earth Supervised	Earth Monitored	Autonomous Rendezvous & Dock	Earth Monitored
	Exploration EVA	System Testing	Limited Duration	Full Duration	Full Duration	Full Duration	Frequent EVA
Staying Healthy	Crew Health	Long Duration	Short Duration	Long Duration	Dust Toxicity	Long Duration	Long Duration
	Environmental Control & Life Support	Long Duration	Short Duration	Long Duration		Long Duration	Long Duration
	Radiation Safety	Increased Understanding	Forecasting	Forecasting Shelter	Forecasting Shelter	Forecasting Shelter	Forecasting & Surface Enhanced
Transportation	Ascent from Planetary Surfaces				Sub-Scale MAV	Sub-Scale MAV	Human Scale MAV
	Entry, Descent & Landing				Sub-Scale/Aero Capture	Sub-Scale/Aero Capture	Human Scale EDL
	In-space Power & Prop		Low power	Low Power	Medium Power	Medium Power	High Power
	Beyond LEO: SLS & Orion		Initial Capability	Initial Capability	Full Capability	Full Capability	Full Capability
	Commercial Cargo & Crew	Cargo/Crew	Opportunity	Opportunity	Opportunity	Opportunity	Opportunity
	Communication & Navigation	RF	RF & Initial Optical	Optical	Deep Space Optical	Deep Space Optical	Deep Space Optical
		EARTH RELIANT	PROVING GROUND			EARTH INDEPENDENT	

Specific Habitation System Objectives

System	Includes	Today	Deep Space Goal
Life Support	Air revitalization, water recovery, waste collection and processing	42% recovery of O_2 from CO_2; 90% recovery of H_2O; <6 mo MTBF for some components	>75% recovery of O_2 from CO_2; >98% recovery of H_2O; >2 yr MTBF
Environmental Monitoring	atmosphere, water, microbial, particulate, and acoustic monitors	Limited, crew-intensive on-board capability; rely on sample return to Earth	On-board analysis capability with no sample return; identify and quantify species and organisms in air & water
Crew Health	exercise equipment, medical treatment and diagnostic equipment, long-duration food storage	Large, cumbersome exercise equipment, limited on-orbit medical capability, food system based on frequent resupply	Small, effective exercise equipment, on-board medical capabilities, long-duration food system
EVA	Exploration suit	ISS EMU's based on Shuttle heritage technology; not extensible to surface ops	Next generation spacesuit with greater mobility, reliability, enhanced life support, operational flexibility
Fire	Non-toxic portable fire extinguisher, emergency mask, combustion products monitor, fire cleanup device	Large CO_2 suppressant tanks, 2-cartridge mask, obsolete fire products. No fire cleanup other than depress/repress	Unified fire safety approach that works across small and large architecture elements
Radiation Protection	Low atomic number materials including polyethylene, water, or any hydrogen-containing materials	Node 2 CQ's augmented with polyethylene to reduce the impacts of trapped proton irradiation for ISS crew members	Solar particle event storm shelter based on optimized position of on-board materials and CQ's with minimized upmass to eliminate major impact of solar particle event on total mission dose

Selected Critical Time Frames and Decisions

DECISIONS MADE & IMPLEMENTATION UNDERWAY	DECISIONS TO BE MADE IN NEXT FEW YEARS, IN WORK NOW	DECISIONS TO BE MADE IN THE NEXT DECADE, FED BY STUDIES IN PROGRESS
• Extended ISS operations to at least 2024 using ISS to develop and test long duration highly reliable life support and monitoring systems. Understand and develop ways to keep the crew healthy for long durations of microgravity exposure. • Pursue an evolvable SLS via Exploration Upper Stage and then advanced solid rocket boosters • Selected an ARM baseline mission to return an asteroidal boulder to lunar orbit for subsequent crew rendezvous and exercise high-power SEP • Defined and initiated key technology studies	• Allocate Flight Test and Proving Ground objectives to post-EM2 missions • Deep-space habitation capability selected based on ISS results • Select in-space transportation systems approach (split cargo, Lunar departure, etc.) • Identify future Mars robotic precursor missions beyond Mars 2020 • Established key standards for exploration systems • Develop an exploration EVA suit for use on Orion missions	• Select initial human missions beyond the Proving Ground • Identify the role of ISRU in the overall logistics strategy • Demonstrate higher mass EDL and round trip capability • Define and develop robotic Mars preparatory missions • Design Mars surface habitats • Develop Mars surface power generation • Preposition key hardware at Mars

Summary

- Human exploration of Mars is achievable by taking the long view
- We are putting the right pieces in place
  - Conducting research and technology demonstrations on ISS
  - Making great progress toward the first missions of SLS/Orion
  - Advancing key capabilities and technologies, e.g., ARM/SEP
  - Planning the transition from LEO to the Proving Ground of cislunar space, e.g., advancing habitation systems and capabilities
  - Conducting the architecture trades and technology developments needed to enable Earth-independent exploration beyond the Earth-moon system
- We are building a long term sustainable program of human exploration

BACK UP

Preliminary Top-Level Phase 0 - 1 - 2 Objectives

Phase 0: Exploration Research and Systems Testing on ISS

- Test Mars-capable **habitation systems** – Environmental Control and Life Support System (ECLSS), environmental monitoring, crew health equipment, exploration generation Extravehicular Activity (EVA) suit, fire detection/suppression, radiation monitoring
- Complete **human health & performance** research and risk reduction activities
- Demonstrate **exploration related technologies and operations**
  - Autonomous crew operations
  - Docking, prox ops

enables

- Robotic manipulation technology and techniques demonstrations
- Remote presence technology development and demonstrations
- Earth/space science
- Enable development of Low Earth Orbit (LEO) commercial market

Phase 1: Cislunar Flight Testing of Exploration Systems

- Demonstrate that **Space Launch System (SLS) and launch processing systems** can insert both Orion and co-manifested payloads into cis-lunar space
- Demonstrate that **Orion and mission operations** can conduct crewed missions in cis-lunar space at least for 21 days
- Demonstrate **Mars-extensible systems and mission operations** that reduce risk for future deep space missions (with EVA) beyond 21 days

enables

- Validate cislunar as staging orbits
- Use of high power Solar Electric Propulsion (SEP) for deep space missions
- Asteroid related origins of the solar system science objectives
- Demonstrate real-time robotic lunar surface activities
- In situ resource utilization demonstrations

Phase 2: Cislunar Validation of Exploration Capability

- Validate **Mars class habitation** and habitation system functionality and performance
- Validate **Mars class human health and performance**
- Validate operational readiness to leave Earth-Moon system via **one year+ "shakedown cruise"** (no resupply/crew exchanges, limited ground interaction, etc.)

enables

- Origins of the universe, lunar rover volatile sample return
- Other scientific or research objectives?

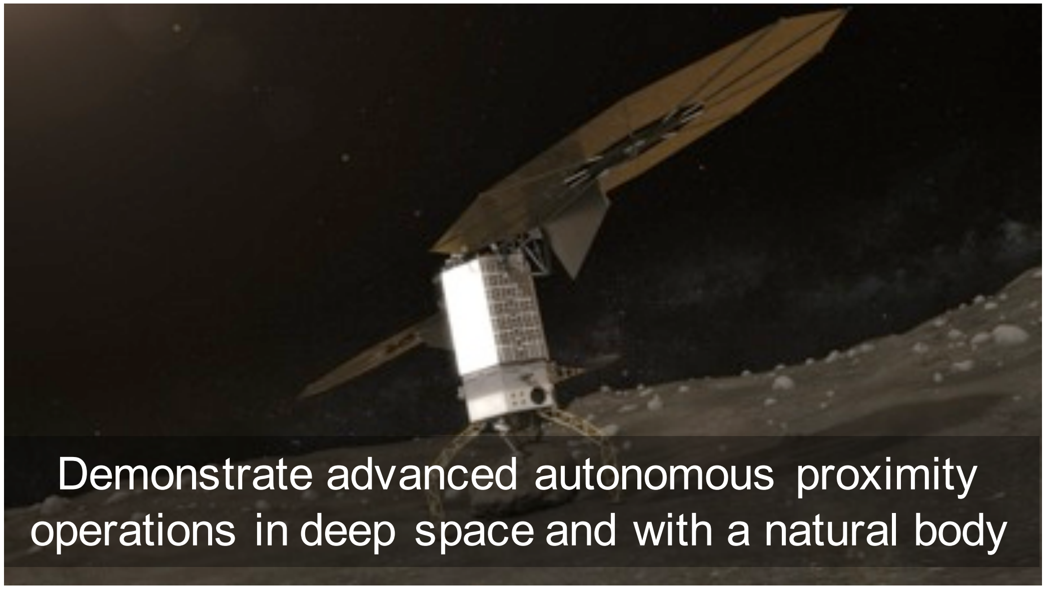
ISS End-of-Life Considerations

- **Instead of declaring a definite end date for ISS, NASA will focus on considerations such as:**
  - Short term crewed habitation missions are being executed in cis-lunar space while ISS is still operational and being utilized
  - Exploration research and technology/system development activities requiring ISS as a testbed are essentially complete
  - There is an expanded commercial market and broad private/government/academic demand for Low Earth Orbit (LEO)-based platforms that are based on private and/or public/private business models
  - Value benefit of the ISS has been sufficiently achieved
  - Maximizing international ISS partnership and participation
  - Safe sustainment of the ISS will remain paramount

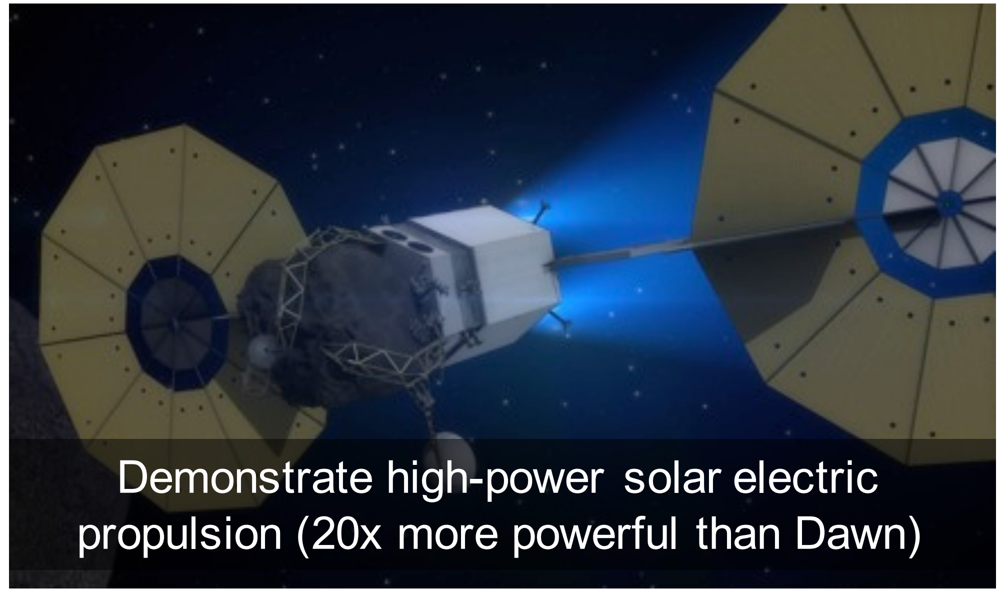
Proving Ground Phase 1 Flight Test Objectives

CATEGORY	FLIGHT TEST OBJECTIVE
Transportation	Demonstrate Orion's capability to extract co-manifested payload from SLS fairing.
Transportation	Determine Orion's ability to support missions with at least 4-Crew longer than 21 days in conjunction with additional elements.
Transportation	Evaluate Orion's depress/repress for EVA contingency operations.
Transportation	Evaluate Orion's off-axis (tail-to-sun) performance.
Transportation	Evaluate EUS TLI Performance with Orion plus Co-Manifested Payload.
Transportation	Evaluate high-power electric propulsion systems.
Transportation	Evaluate high-efficiency, high-power solar arrays in deep space.
Transportation	Demonstrate Earth-independent deep space navigation.
Operations Working in Space	Demonstrate transition between crewed and uncrewed operations, including configuration for remote/dormant operations and reactivation for crewed support.
Operations Working in Space	Demonstrate human spacecraft operations in the presence of communications latency.
Operations Working in Space	Demonstrate independent (On-board) mission and trajectory design/planning capability.
Operations Working in Space	Evaluate stowage strategies to handle logistics and trash within available stowage volume for deep space missions.
Operations Working in Space	Demonstrate side-by-side human and robotic operations.
Exploration Working in Space	Demonstrate collection and return of geologic asteroid samples.
Exploration Working in Space	Demonstrate research sample acquisition, handling, analysis, and curation requiring environmentally controlled conditions with no cross-contamination permitted.
Habitation Staying Healthy	Demonstrate crew accommodations for Beyond-LEO conditions.
Habitation Staying Healthy	Evaluate the performance of electrical components in a deep-space radiation environment.
Habitation Staying Healthy	Evaluate cislunar transit habitat airlock and EVA system servicing accommodation for ability to support contingency EVA operations.
Habitation Staying Healthy	Evaluate cislunar transit habitat airlock and EVA system servicing accommodation for ability to support nominal deep space mission EVA operations.
Crew Health Staying Healthy	Demonstrate/evaluate space radiation protection and monitoring.
Crew Health Staying Healthy	Demonstrate/evaluate human health, performance, and environmental health in a hostile and closed environment.
Crew Health Staying Healthy	Evaluate the effects of deep space on complex organisms, plants, food, medicines, and animal models.

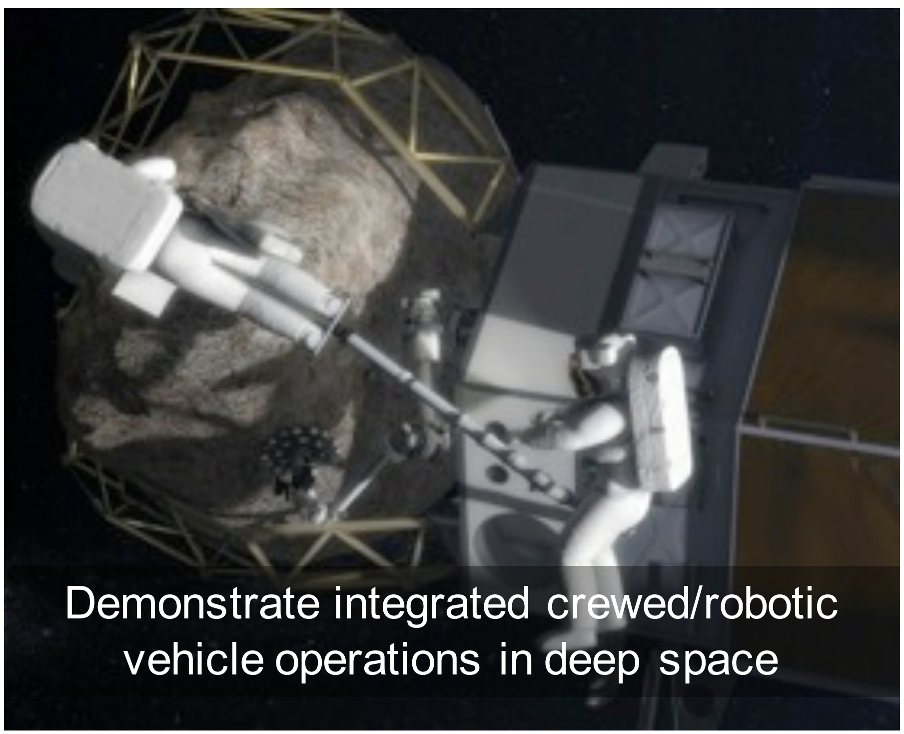
ARM Objectives in Support of Human Exploration



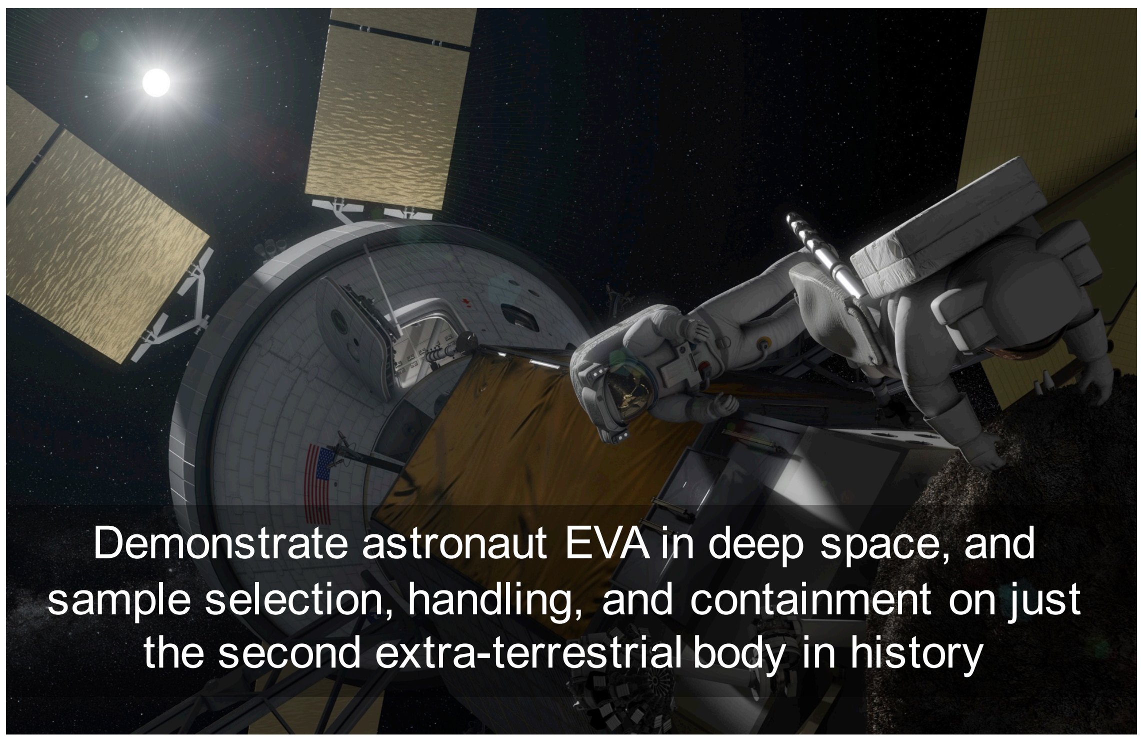
Demonstrate advanced autonomous proximity operations in deep space and with a natural body



Demonstrate high-power solar electric propulsion (20x more powerful than Dawn)

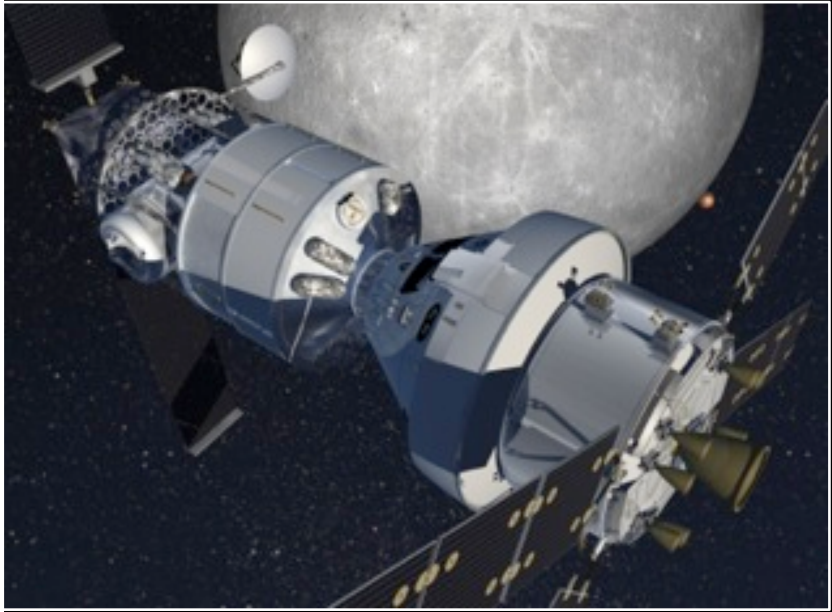


Demonstrate integrated crewed/robotic vehicle operations in deep space

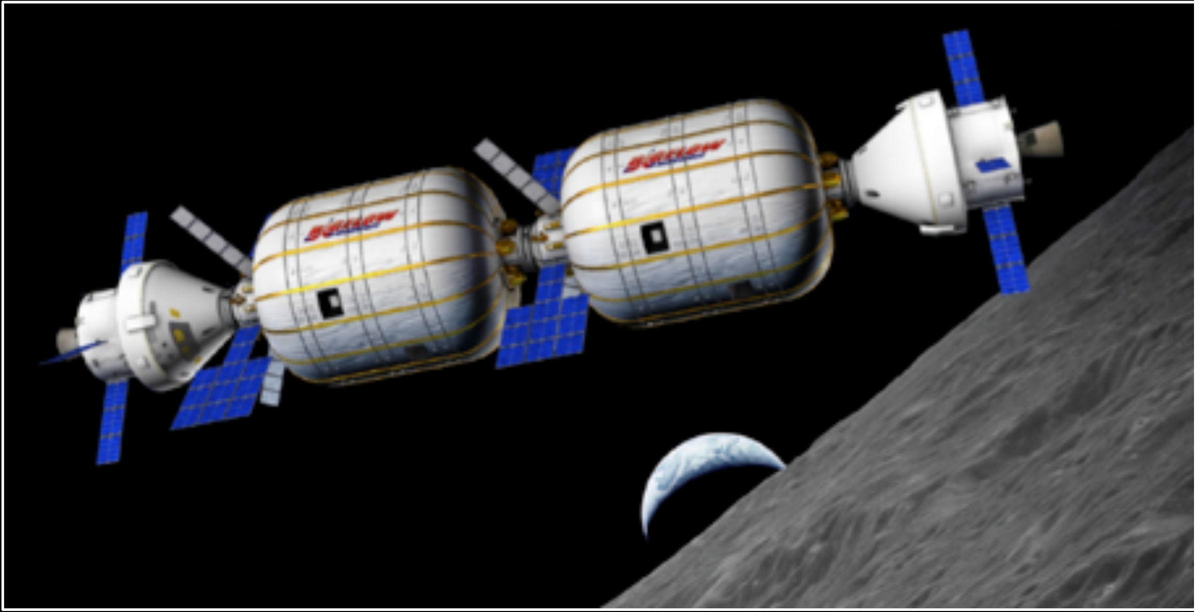


Demonstrate astronaut EVA in deep space, and sample selection, handling, and containment on just the second extra-terrestrial body in history

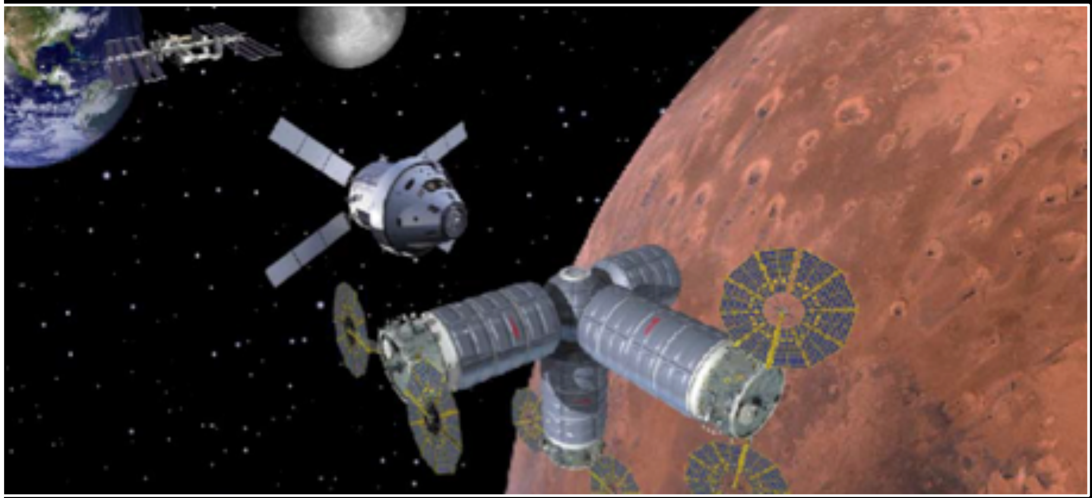
NextSTEP BAA: Habitation Awards (Habitats)



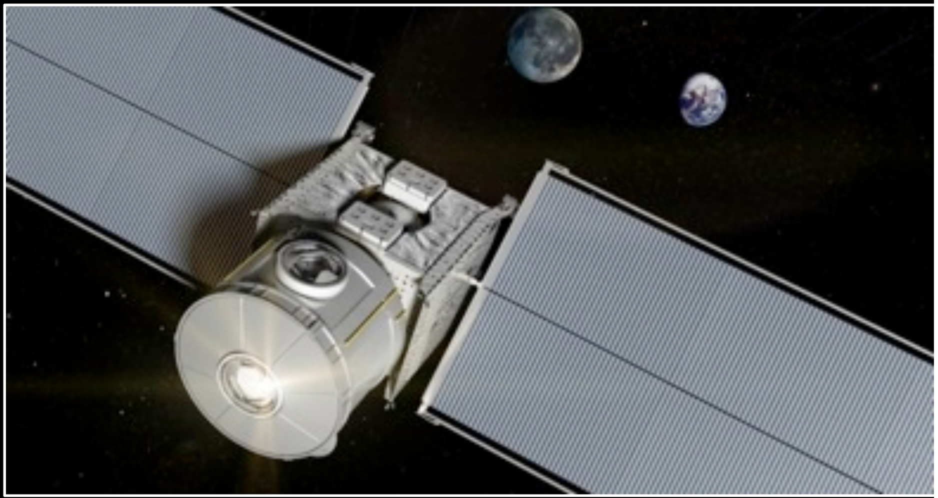
Lockheed Martin | Denver, CO



Bigelow Aerospace LLC | Las Vegas, NV



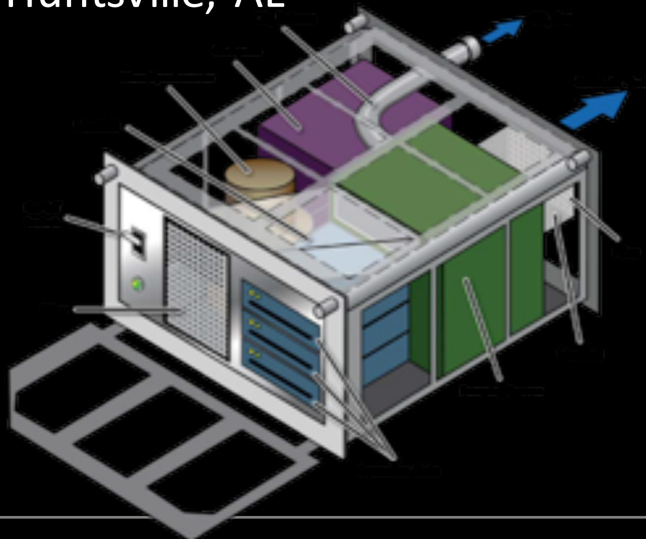
Orbital ATK | Dulles, VA



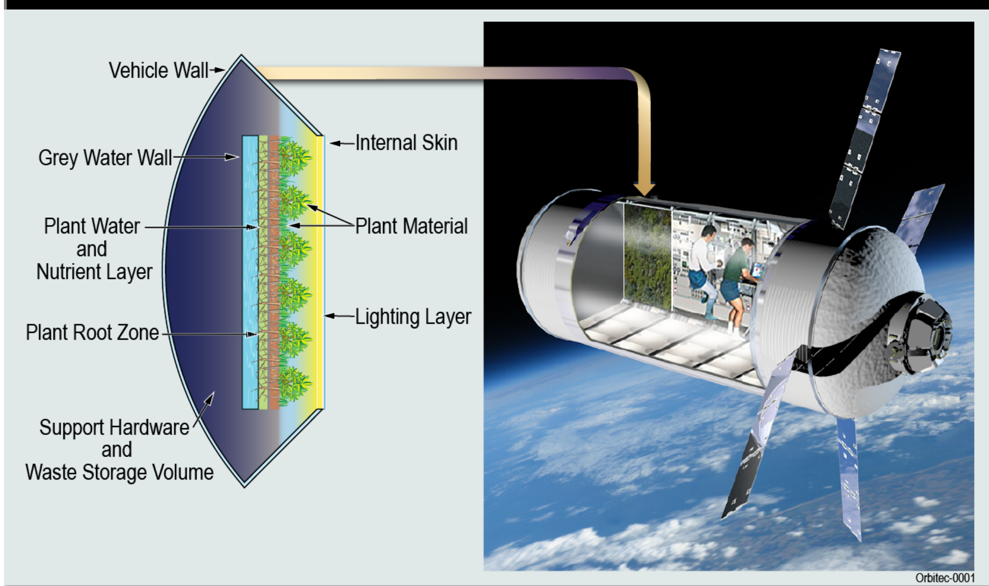
Boeing | Houston, TX

NextSTEP BAA Habitation (ECLSS)

Dynetics, Inc | Huntsville, AL

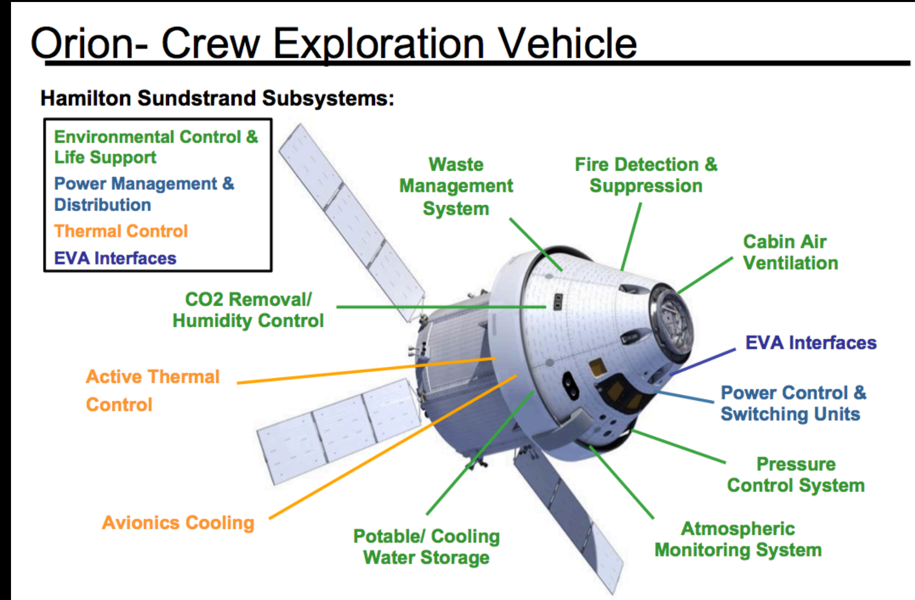


Orbitec | Madison, WI



Hamilton Sundstrand Space Systems International

Windsor Locks, CT



	EMC Focus Question	Current Areas of Study	Status
A	**How do we pioneer an extended human presence on Mars that is Earth independent?**	• Reusable, long-life, refurbishable and refuelable elements • Build-up scenarios for ISRU to reduce logistics chain and increase sustainability	• Refining habitat and transportation stage concepts • Evaluating campaign w/ ISRU fueled in-space transportation system • Assessing water-rich Mars architecture impacts
B	**What are the objectives, engineering, and operational considerations that drive Mars surface landing sites?**	• Mars exploration and science objectives for increasing durations • Landing Site Requirements and Constraints	• Evaluating sites proposed from Oct 2015 EZ workshop • Assessing mass estimates for surface tunnel and power cabling • Evaluating surface power trades
C	**What sequence(s) of missions do we think can meet our goals and constraints?**	• Campaign concepts that satisfy the strategic principles	• Assessing more minimalist approach and campaign impacts • Assessing later dates for crewed Mars orbit missions
D	**Is a reusable Mars transportation system viable?**	• Repurposing of ARV capabilities • Reuse of habitat, propulsion stages - 1100 day habitat refurbishment and reusable SEP for multiple missions	• Assessing refueling, refurbishment, and recertification in cislunar of habitat and SEP • Commercial launch of propellants implication on SLS launch rate
E	**Can ARV derived SEP support Mars cargo delivery requirements?**	• Evolved ARV to transport cargo and optionally crew to Mars vicinity and return safely (41mt roundtrip with crew)	• Performing SEP propulsion system refinement and assessing system consistency with evolved ARV capabilities
F	**How can we maximize commonality across Mars ascent, Mars vicinity taxi, exploration vehicle and initial deep-space habitation component?**	• Minimal common MAV be used for Mars Taxi, Mars Moon Exploration vehicle, & surface rover? • Trade study of propulsion system (LOx/CH4 and Hypergols)	• Defining smallest credible MAV cabin and assessing commonality across the architecture • Assessing whether a fueled ascent stage can be landed in combination with an orbital taxi/boost stage
G	**What are the required capability investments for the EMC over the next five years?**	• Capability development prior to sending crew to Mars vicinity • Capabilities and FTOs for ISS testing • Capabilities and FTOs for cislunar testing	• Defining Proving Ground satisfaction criteria • Refining SMT capability roadmaps • Quantifying development efforts and required ISS and cislunar testing

	EMC Focus Question	Current Areas of Study	Status
H	**What is the appropriate habitation system?**	• Assess 1,100-day habitat that is less than 41mt with logistics/spares for crew of 4 • Identify evolvability and of functional requirements of Mars hab system	• NextSTEP BAA • Assessing various initial cislunar habitation concepts (commercial, international, internal)
I	**Is Phobos a viable human target?**	• Explore via teleops from orbit and addition of a short duration excursion mission • Options for sample acquisition and handling	• Precursor SKG identification • Developing data-driven functional requirements and ops concepts for robotic tasks as a function of comm latency • Assessing extra mass capability beyond what is needed for a taxi
J	**What are potential Mars surface pathfinder concepts?**	• With SMD and OCT, identify potential orbital and lander pathfinder concepts	• Integrating performance assessments and conops for 3 Mars EDL concepts • Assessing viability of solar power for Mars ISRU demo if needed • Trade single pathfinder mission to Mars vs multiple Earth based tests
K	**What capabilities are needed to enable elements to survive long dormancy periods in space?**	• Cislunar aggregation concepts and Mars system pre-deploy missions with associated dormancy periods	• Assessing Phobos hab and lander integration with transportation system in cislunar • Evaluating capability of the hab propulsion system to sustain until aggregation • Evaluating pre-deploy dormancy needs
L	**What communications capabilities are needed?**	• Comm needs for Proving Ground and Mars Vicinity	• Assessing other architecture elements (SEP bus) to provide comm and station keeping • Communications deployment strategy
M	**Can humans safely perform 1100 day missions in deep space?**	• Risk mitigation systems and operational approaches to keep crew safe for Mars vicinity missions	• Using data from 1 year ISS mission • Proposed additional long duration Mars analog missions on ISS
N	**Can there be synergy between landers for multiple planetary surfaces?**	• Surface exploration with 5mt, 8mt or 20mt lander • EDL system for 20mt lander	• Evaluating various lander sizing concepts including crew cabin configurations; crews with minimal canopy; hypergols vs methane; refueling and ISRU; descent issues; impacts to campaign risk

System Maturation Teams

Subject Matter Experts from across the agency who have been involved in maturing systems and advancing technology readiness for NASA.

SYSTEM MATURATION TEAM — CAPABILITIES LIST —
Autonomous Mission Operations (AMO)
Communication and Navigation (Comm/Nav)
Crew Health & Protection and Radiation (CHP)
Environmental Control and Life Support Systems and Environmental Monitoring (ECLSS-EM)
Entry, Descent and Landing (EDL)
Extra-vehicle Activity (EVA)
Fire Safety
Human-Robotic Mission Operations (Robotics)
In-Situ Resource Utilization (ISRU)
Power and Energy Storage (Power)
Propulsion
Thermal (including cryo)
DISCIPLINE TEAM - CROSSCUTTING
Avionics
Structures, Mechanisms, Materials and Processes (SMMP)
Dormancy Operations

- Define performance parameters and goals for each capability
- Develop maturation plans and roadmaps for the identified performance gaps, specifying the interfaces between the various capabilities, and ensuring that the capabilities mature and integrate to enable future pioneering missions. The subject matter experts that compose each SMT are responsible for understanding their capabilities across all missions and elements within the Evolvable Mars Campaign.
- Work closely with the Space Technology Mission Directorate, Evolvable Mars Campaign, Chief Technologist, Chief Scientist, Capability Leadership Teams to coordinate capability needs and gaps

One-Year Mission (1YM) & Twin Study

SCIENCE ACCOMPLISHMENTS

1YM Crew participated in 22 investigations (18 HRP-led, 2 IBMP-led, 2 JAXA-led)

- Kelly completed 74 in-flight test sessions
- Kornienko completed 41 in-flight test sessions
- 459 total samples collected
  - 103 blood (450 ml)
  - 186 urine (1.3 L)
  - 170 saliva, perspiration, water, surface swabs
  - 8 fecal
- Included in 1081 frozen samples coming down on SpaceX 8

Flagship joint HRP/IBMP investigations

- Fluid Shifts
  - 3 full inflight sessions (US hardware in Zvezda)
- Field Test
  - Both crewmembers tested in tent at landing site
  - Kelly also tested in Norway, Houston

U.S. Twins Investigation

- 10 projects, 5 new to NASA
- Wide-spectrum survey from chromosome (DNA, RNA) through proteome and metabolome, to immune, cardiovascular and central nervous systems and microbiome

LESSONS LEARNED

- Fully-integrated multilateral plans by L-22 months
- Partner agencies must establish, respect deadlines, requirements, documentation needs
- All levels of all partner management must be engaged and supporting

PUBLIC INTEREST

- 36 interviews during last 2 weeks of 1YM
- 3 NASA PAO events
- All coverage favorable

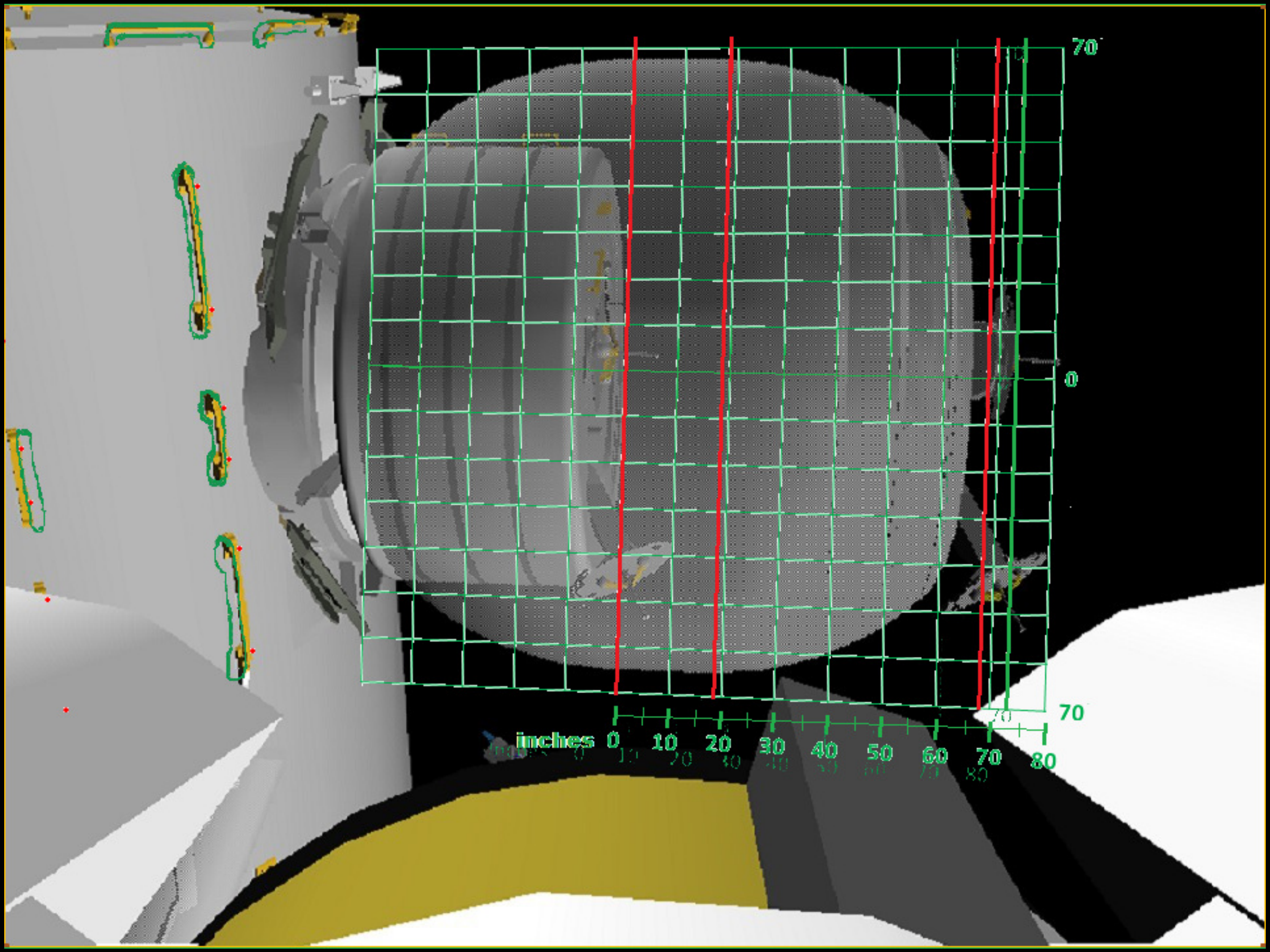
POST-FLIGHT DATA COLLECTION/DISSEMINATION PLAN

- Preliminary results by ~R+30
- Most post-flight testing to be completed by R+180
- Twins samples to be batch processed; BDC continues until R+9 months
- Publications expected after February 2017
  - Small n (1YM, Twins) compromises confidentiality, requires crewmember informed consent after data review

FOLLOW-ON ONE-YEAR MISSIONS

- HRP requires 5 more 1YM coordinated with 2-month taxi flights (2MM) and 6-month standard expeditions (6MM)
- “Standard Measures” core to track cross-duration variations, supplemented by specific investigations for greater insight
- HRP ready to start ASAP
- HRP and ISSP socializing within NASA and with IPs

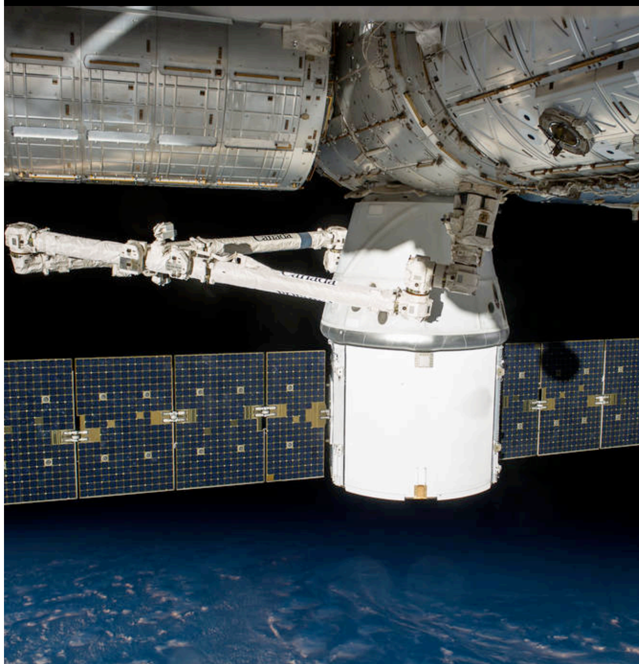
Demonstrating Technologies For Deep Space Habitation: Bigelow Expandable Activity Module



Launching on SpaceX CRS-8

Commercial Cargo Resupply Services 2

NASA



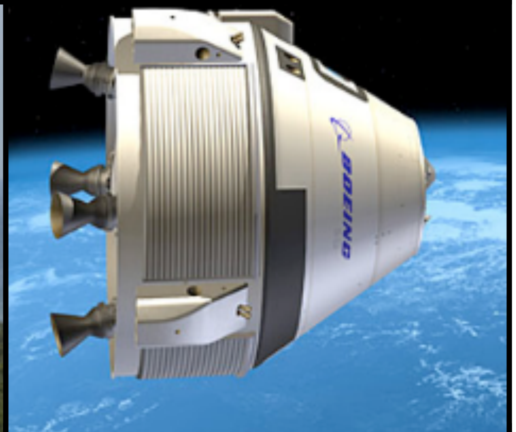
SPACEX

SNC SIERRA NEVADA CORPORATION
Space Systems

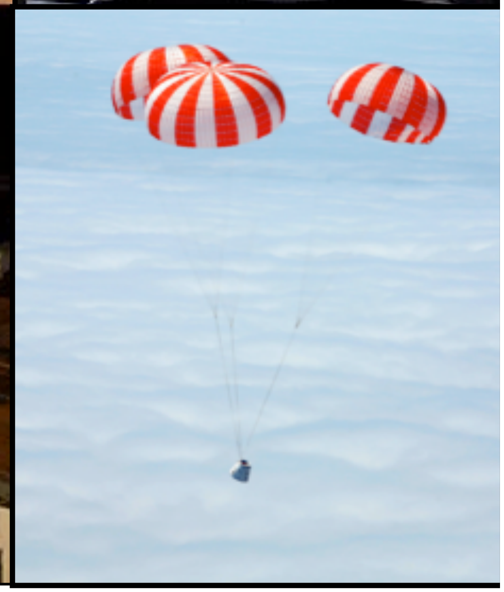
Orbital ATK

Commercial Crew: U.S. Transportation to ISS

Boeing



Space-X

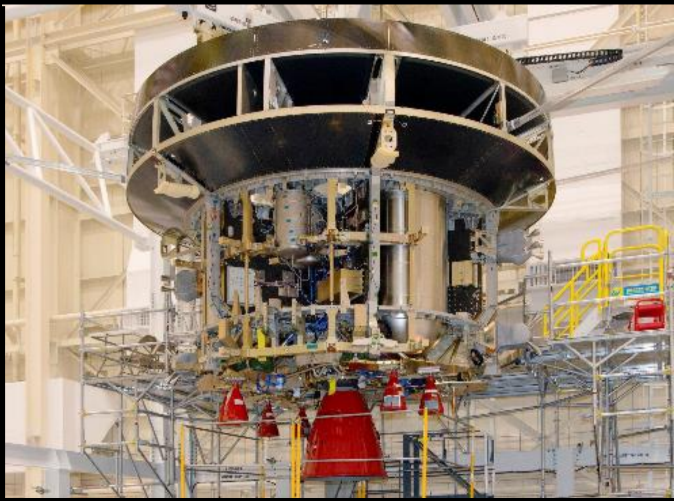



Commercial Crew Transportation Capability Contract
underway with initial flights planned for 2017

Orion Accomplishments

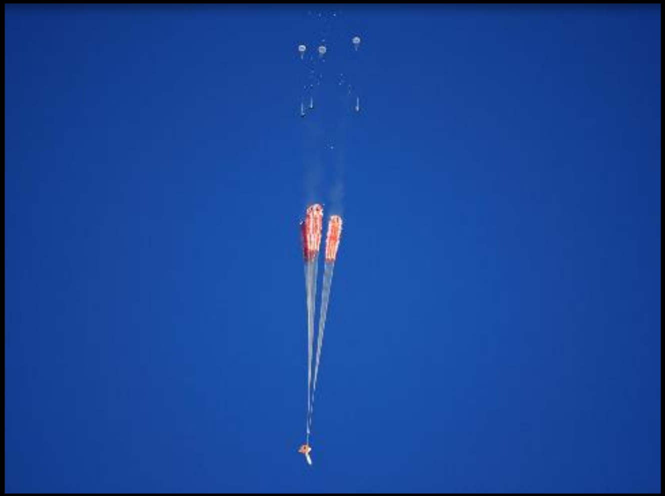
Orion EM-1 crew module pressure vessel welding is completed at Michoud Assembly Facility in New Orleans

The completed pressure vessel arrives at the Operations and Checkout Building at the Kennedy Space Center

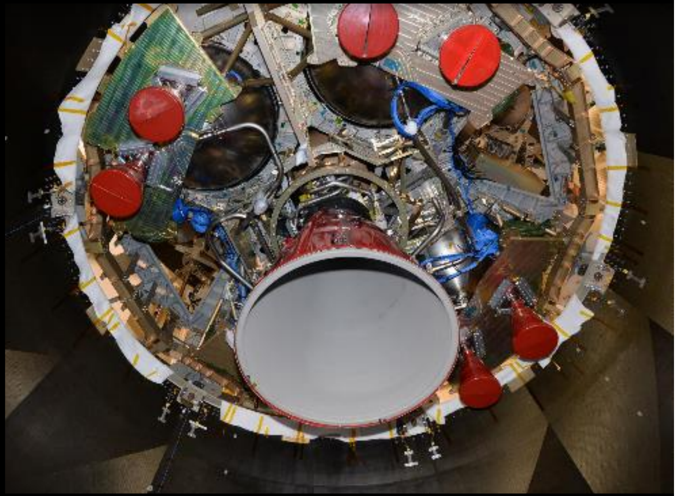


European Service Module Structural Test Article (ESM STA) at Glenn Research Center Plum Brook Station in Ohio

Launch Abort Motor structural qualification test at Orbital ATK in Utah



Final Engineering Parachute Drop Test, Army Yuma Proving Ground in Arizona



Orbital Maneuvering Engine on the ESM STA at Glenn Research Center Plum Brook Station in Ohio

Space Launch System Accomplishments

Launch Vehicle Stage Adapter
Test Article Fabrication

Nozzle installation into the aft
booster segment for QM-2

RS-25 flight engine 2059 installed for testing
at Stennis Space Center

Steel towers rising for new SLS test stands at
Marshall Space Flight Center

SLS Core Stage test article progress,
Michoud Assembly Facility

Interim Cryogenic Propulsion Stage test
article complete

Ground Systems Development Accomplishments

First Work Platform for Space Launch System Installed in Vehicle Assembly Building (VAB)

Conducted the Critical Design Review

Completed Phase A Testing of the Orion Service Module Umbilical

Started Construction of Flame Trench at Launch Pad B

Completed Command and Control Software Release 3.2

Received First Shipment of Booster Pathfinder Hardware for V&V Testing at Rotation, Processing and Surge Facility (RPSF)