Human Exploration and Operations Mission Directorate

FY 2016 Budget Overview

William H. Gerstenmaier
Associate Administrator

April 2015

Human Exploration and Operations

Agenda

- FY 2016 Budget Overview
- Program
  - International Space Station
  - Commercial Crew
  - **Exploration Systems Development**
  - **Exploration Research and Development**
    - **Human Research Program**
    - **Advanced Exploration Systems**
  - **Space Flight Support**
    - **Space Communications and Navigation**
    - **Rocket Propulsion Test**
    - **Launch Services Program**
    - **Human Space Flight Operations**
    - **21st Century Space Launch Complex**

Human Exploration and Operations

Budget Overview

- FY 2016 budget submit provides $8.5 billion for Human Exploration and Operations (HEO) to continue pursuit of NASA goals, consistent with the NASA Authorization Act of 2010:
  - Sustain the capability for long duration presence in low Earth orbit
  - Expand permanent human presence beyond low Earth orbit
  - 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; enhance capabilities required for future missions
- Enables continued research aboard International Space Station (ISS) that advances technologies required for future long duration missions
  - Extend ISS life to at least 2024; utilize as research platform to ensure that crew can travel safely beyond low Earth orbit, and develop technological capabilities needed for long duration missions

Human Exploration and Operations

Budget Overview (continued)

- Funds purchase of reliable ISS cargo resupply services from US private sector companies; partners with industry to develop American capabilities for commercial crew systems
  - By end of 2017, provide US commercial crew capability to ISS, reducing reliance on foreign partners
  - Total of two post-certification missions are funded by Commercial Crew Program; remaining are funded by ISS
- Enables ISS use as a National Laboratory
- Enables commercial demand driven market in low Earth orbit (transportation and commercial research uses)
- Funds next generation launch and crew vehicles, and associated ground systems necessary to extend human presence beyond low Earth orbit
  - Develop initial capabilities required for human exploration beyond low Earth orbit, including Space Launch System (SLS), Orion crew vehicle, and Exploration Ground Systems (EGS)

Human Exploration and Operations

Budget Overview (continued)

- Builds on sustainable exploration strategy
  - Enable variety of deep space exploration missions, with eventual pioneering missions to Mars
  - Prepare for early crewed demonstration mission in the proving ground with SLS and Orion
  - Support capabilities for more complex missions in future
- Supports human health and technological research vital to future deep-space exploration and life on Earth
  - Research and investigate crew health and advanced technologies on ISS and other platforms
- Continues modernization/enhancement of enabling capabilities critical to operations and exploration in and beyond low Earth orbit
  - Deliver and enhance critical space communications and navigation services to support customer missions
  - Provide affordable and reliable access to space for NASA missions, and US government or government-sponsored missions
  - Enable supporting activities and infrastructure required for space flight operations

Human Exploration and Operations

Program Financial Plan

Budget Authority ($ in Millions)	*FY 2014	**FY 2015	FY 2016	***FY 2017	***FY 2018	***FY 2019	***FY 2020
Human Exploration and Operations	**7,887.2**	**8,184.5**	**8,509.6**	**8,673.4**	**8,803.6**	**8,935.5**	**9,069.7**
Exploration	**4,113.2**	**4,356.7**	**4,505.9**	**4,482.2**	**4,298.7**	**4,264.7**	**4,205.4**
Exploration Systems Development	3,115.2	3,245.3	2,862.9	2,895.7	2,971.7	3,096.2	3,127.1
Orion Program	1,197.0	1,194.0	1,096.3	1,119.8	1,122.9	1,126.7	1,138.0
Space Launch System	1,600.0	1,700.0	1,356.5	1,343.6	1,407.6	1,516.5	1,531.6
Exploration Ground Systems	318.2	351.3	410.1	432.3	441.2	453.0	457.5
Commercial Spaceflight- Commercial Crew	696.0	805.0	1,243.8	1,184.8	731.9	173.1	1.1
Exploration Research and Development	302.0	306.4	399.2	401.7	595.1	995.4	1,077.2
Human Research Program	149.4	-	167.8	170.3	178.2	178.2	180.0
Advanced Exploration Systems	152.7	-	231.4	231.4	416.9	817.2	897.2
Space Operations	**3,774.0**	**3,827.8**	**4,003.7**	**4,191.2**	**4,504.9**	**4,670.8**	**4,864.3**
International Space Station	2,964.1	-	3,105.6	3,273.9	3,641.0	3,826.0	4,038.3
ISS Systems Operations and Maintenance	1,236.1	-	1,106.1	1,194.5	1,327.7	1,321.3	1,327.6
ISS Research	330.7	-	394.0	362.3	364.2	370.6	376.8
ISS Crew and Cargo Transportation	1,397.3	-	1,605.5	1,717.1	1,949.1	2,134.1	2,333.9
Space and Flight Support (SFS)	809.9	-	898.1	917.3	863.8	844.8	826.1
21st Century Space Launch Complex	39.6	-	23.3	11.8	-	-	-
Space Communications and Navigation	538.5	-	632.4	659.7	616.6	597.6	576.4
Human Space Flight Operations	106.5	-	108.5	110.2	110.5	110.5	111.6
Launch Services	80.9	-	86.7	88.0	89.1	89.1	90.0
Rocket Propulsion Test	44.4	-	47.2	47.6	47.6	47.6	48.0
Construction and Environmental Compliance	**169.5**	**70.9**	**36.2**				
Exploration	139.3	52.3	10.0				
Orion Program	3.0	-	-				
Space Launch System	23.2	-	5.0				
Exploration Ground Systems	113.1	52.3	5.0				
Space Operations	30.2	18.6	26.2				
International Space Station	-	-	6.0				
21st Century Space Launch Complex	7.7	4.8	2.6				
Space Communications and Navigation	16.9	13.8	17.6				
Launch Services	3.2	-	-				
Rocket Propulsion Test	2.4	-	-				

**FY 2014 reflects funding amounts specified in the June 2014 Operating Plan per P.L. 113-76.*

***FY 2015 reflects only funding amounts specified in P.L. 113-235, the Consolidated and Further Continuing Appropriations Act, 2015.*

****FY 2017 – FY 2020 are notional*

International Space Station

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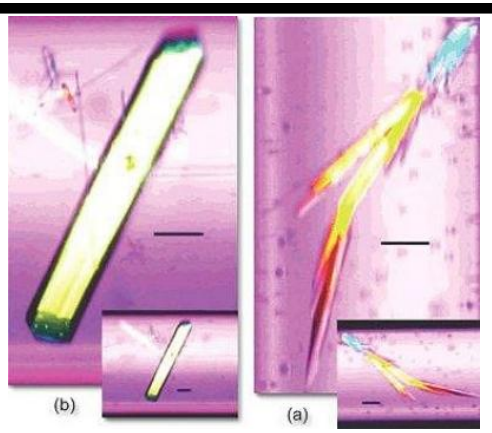
International Space Station: Plans for FY 2015 - FY 2016

- Center for Advancement of Science in Space (CASIS)
  - Leverage microgravity environment to grow commercial research interest in protein crystal growth and disease models to aid study of human diseases such as Huntington's, cystic fibrosis, Amyotrophic Lateral Sclerosis (ALS), and others
  - Sponsor multiple stem cell investigations focused on application of microgravity to grow stem cells for therapeutic use in treatment of heart disease, stroke, spinal cord and traumatic brain injury, among others
  - Leverage microgravity environment to grow commercial interest in technology development for drug discovery and delivery using microfluidic systems



Crystals in a microgravity environment (b) can grow bigger and stronger than those grown on Earth (a). Six separate CASIS-sponsored protein crystal growth studies launched on SpX-3.

- Complete development and begin operation of NASA GeneLab database in 2015
  - For the first time, NASA biological flight data will be available in searchable, public accessed website enabling academia, industry, and other agencies to retrieve and analyze science conducted on organisms flown in space
- Enable new multi-generational, long duration fruit fly laboratory research on ISS to aid in human research (fruit flies share 77% of human disease genes)
  - Facilitate research on various physiological systems, including immune systems development and effects of radiation

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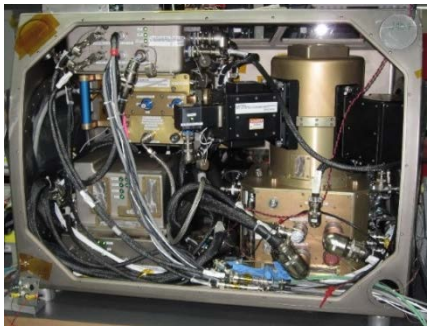
International Space Station: Plans for FY 2015 - FY 2016 (continued)

- Perform Rodent Research-1 Mission
  - Validate improved NASA rodent transportation and habitat units for 30 day ISS missions, featuring commanding/monitoring from ground, video and downlink capability, better access
  - Highlight and validate on-orbit data collection techniques
  - Combine hardware validation with CASIS scientific investigation for muscle atrophy of muscle sparing in transgenic mice
- Announced selections from Cold Atom Laboratory (CAL) NASA Research Announcements, including 5 principal investigator teams with three Nobel laureates
  - CAL multiuser facility designed to study ultracold quantum gases in microgravity environment; available not earlier than September 2016 with launch not earlier than December
  - Passed Critical Design Review in February 2015
- Conduct zero boil off tank (ZBOT) fluids investigation to provide updated computer models applicable to current research on reducing propellant launch mass and improving existing cryogen storage system designs

NASA rodent habitat module, shown with both access doors open, is a next generation replacement to its predecessor, the animal enclosure module.



ZBOT engineering model installed in the microgravity science glovebox work volume mockup.

Human Exploration and Operations

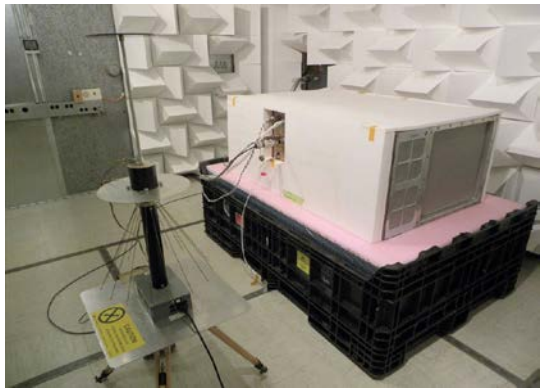
International Space Station: Plans for FY 2015 - FY 2016 (continued)

- Conduct one year ISS study on effects of long-term spaceflight on astronaut Scott Kelly and cosmonaut Mikhail Kornienko
- Perform neuromapping investigation to identify changes in human brain structure and functional human motor control and performance resulting from long duration spaceflight; cognitive and performance testing may also find applications on Earth
- Utilize ocular health medical research to expand understanding of visual impairment and intracranial pressure in-flight on long duration missions
- Demonstrate 3D in-space printing as first step in "machine shop" capability for future exploration
  - Completed initial demonstration with STMD and AES, printing of 25 parts of 14 unique designs, including demonstration of quick turn-around process
  - Conducted nationwide "Future Engineers" student design challenge in partnership with ASME, attracting over 450 submissions
- Conduct Bigelow Expandable Activity Module (BEAM) demonstration supporting AES objective to understand deep space habitat options for human missions beyond Earth orbit

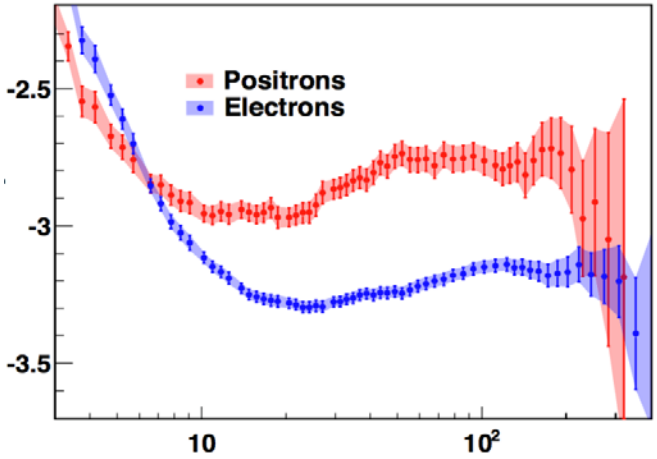
Human Exploration and Operations

International Space Station: Plans for FY 2015 - FY 2016 (continued)

- Conduct series of Saffire project experiments using returning Cygnus vehicles to assess large scale microgravity fires (spread rate, mass consumption, heat release) and verify oxygen flammability limits in microgravity
- Demonstrate deployment of next generation Roll Out Solar Array (ROSA) for potential use on ISS and future exploration missions
- Continue operating Alpha Magnetic Spectrometer (AMS) – a state-of-the-art particle physics detector, constructed, tested and operated by international team
  - Initial AMS positron science results published in *Physical Review Letters* have been referenced in 279 astrophysics/physics publications, and selected by the American Physical Society as a highlight 2013 science publication



Saffire undergoes acoustic testing at Glenn Research Center in Ohio.

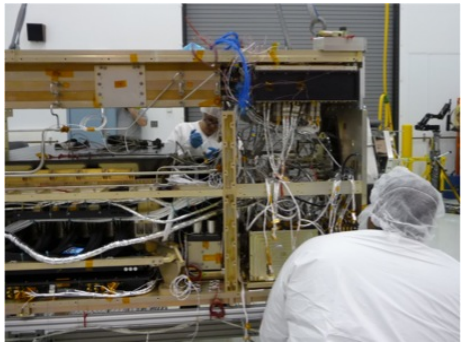


AMS discovered unexplained excess of high-energy positrons in Earth-bound cosmic rays, consistent with positrons originating from annihilation of dark matter particles.

Human Exploration and Operations

International Space Station: Plans for FY 2015 - FY 2016 (continued)

- Perform Cosmic-Ray Energetics and Mass (CREAM) investigation, which measures charges of cosmic rays over a broad energy range
  - Utilizing ISS CREAM data, astrophysicists could improve existing cosmic ray acceleration and propagation models to address long-standing fundamental science questions involving origin, source, and history of cosmic rays



CREAM payload in final assembly and electrical systems testing at WFF.

- Utilize Cloud-Aerosol Transport System (CATS) instrument to provide data on location, composition and distribution of atmospheric constituents (such as pollution), which impact climate on a global scale (launched on SpX-5)
- Use external Multi-Use System for Earth Sensing (MUSES) platform, capable of simultaneously hosting four Earth observation instruments – all robotically serviceable
- Conduct Stratospheric Aerosol and Gas Experiment III (SAGE III) to provide global, long-term measurements of key components of Earth atmosphere to improve understanding of climate, climate change and human-induced ozone trends
  - ISS orbital path will help maximize scientific value of SAGE III observations

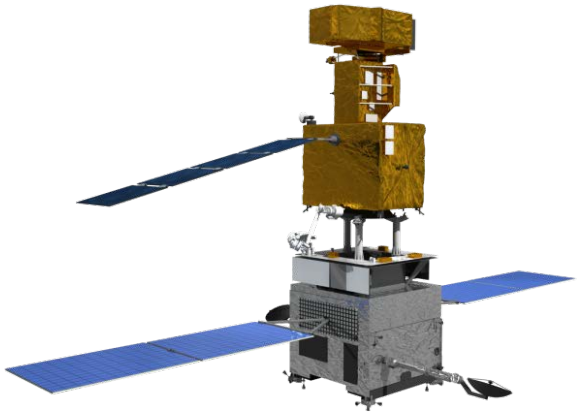
Human Exploration and Operations

International Space Station:
In-Space Robotic Servicing – FY 2015 Plans

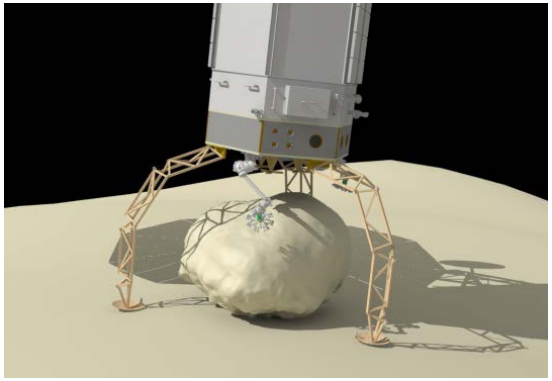
- **Complete Restore-L feasibility study**
  - Conduct spacecraft bus studies
    - Two competitively selected industry vendors (dedicated buses) and US Government owned winged vehicle.
  - Mature mission concept and develop forward plan

- **ARM common technology prototyping**
  - Leverage In-Space Robotic Servicing Restore-L capabilities development
  - Support ARM technical risk reduction and capture system downselect activities
  - Support ARM concept development studies, particularly regarding maturation of boulder acquisition option
  - Mature rendezvous and proximity operations capabilities

- **Complete Raven experiment development**
  - Suite of sensors will view visiting vehicles to mature capabilities for Orion, ARM, and In-Space Robotic Servicing
  - Deliver to DoD Space Test Program for STP-H5 integration



Notional Restore-L concept spacecraft shown servicing Landsat-7.

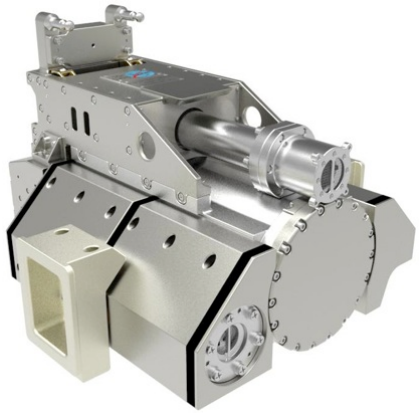


Notional concept ARM boulder acquisition module uses in-space robotic servicing derived dexterous robotics.

Human Exploration and Operations

International Space Station:
In-Space Robotic Servicing – FY 2015 Plans (continued)

- Deliver ammonia leak locator robotic tool for ISS evaluation
  - **U**nit 1 lost in Orb-3 mishap; refurbished unit 2 flight spare prepared for delivery to ISS
- Conduct Robotic Refueling Mission 2 experiment operations on ISS with new task boards and visual inspection poseable invertebrate robot tool
- Continue **Robotic Refueling Mission** 3 development
  - New module to conduct cryogenic fluid and Xenon transfer experiments on ISS



Ammonia leak locator developed as Dextre robotic tool to detect and isolate source of possible gas leaks on ISS; such tools may help reduce future extravehicular activity.

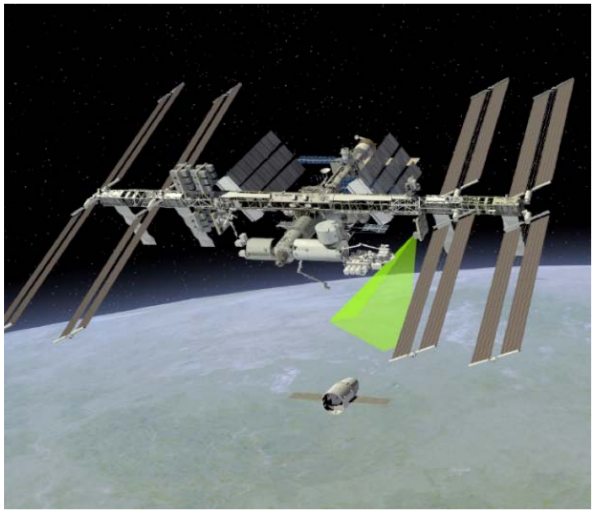
Visual inspection poseable invertebrate robot designed to deliver near and midrange inspection capabilities in space; being tested during second phase of robotic refueling operations on ISS.

New RRM3 fluid transfer module to conduct cryogenic fluid and Xenon transfer experiments on ISS.

Human Exploration and Operations

International Space Station:
In-Space Robotic Servicing – FY 2016 Plans

- Continue Restore-L concept development
- Deliver Raven to ISS and begin experiment operations
  - **Scheduled for flight to ISS as part of US Department of Defense Space Technology program H5 payload in FY 2016**
- Continue RRM-3 development
  - **CDR and integration**
- **Goal is common autonomous rendezvous and docking sensor suite across human spaceflight**



The Raven sensor experiment on ISS includes Vision Navigation System flash lidar, visual and infrared cameras, that will acquire data on visiting vehicles to advance autonomous rendezvous and docking for Orion, ARM and robotic servicing.

Commercial Crew Program

Human Exploration and Operations

Commercial Crew Program

- Facilitate development of US commercial crew space transportation capability
- Achieve safe, reliable, and affordable crew access to and from low Earth orbit, including ISS
- Certify partner vehicles in 2017; SpaceX April-August 2017, Boeing August-October 2017
- Utilize competition to maximize safety and control long-term costs
- Utilize contracts for certification phase to evaluate development results and ensure NASA safety and performance requirements are met
- Awarded Commercial Crew transportation Capabilities (CCtCap) contracts totaling $6.8 billion (maximum contract value) to SpaceX ($2.6B) and Boeing ($4.2B) on September 16, 2014
  - Total of two post certification missions funded by CCP; remaining post certification missions funded by ISS
  - Critical that CCP receive full FY 2016 President's Budget Request to support planned milestones and certification by 2017 to end sole reliance on Russia for US crew transportation
  - Sierra Nevada protested awards September 26, 2014; GAO denied protest January 5, 2015

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Commercial Crew Program:
Cost Effectiveness

- When both of these systems have been completed, and including all previous commercial crew phases, US will have developed two new, independent, human space transportation systems for a cost of less than $5B to the US taxpayer
- Direct price comparison between Soyuz and Commercial Crew for crew transportation not possible
  - Soyuz purchased by “crew seat” while Commercial Crew flights are purchased on per mission basis, which includes four seats and additional 100kg of pressurized cargo
- Equivalent seat price can be calculated for Commercial Crew using prices established in CCtCap contracts for 4-seat configuration, and excluding additional cargo price
- Using CCtCap contract pricing for the 12 Post Certification Missions (6 per company) and assuming all 12 missions are purchased and flown at rate of 2 per year, average price is $58M per seat for Commercial Crew
  - Currently contracted CY 2017 seat price for Soyuz for is approximately $76M per seat
  - Soyuz seat pricing has increased at a rate of approximately 9% per year

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Commercial Crew Program:
Budget Request

Commercial Crew FY 2016 President's Budget Request	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	Total
Total CCiCap Milestone	68.0	-	-	-	-		68.0
Total CCtCap Milestones*	682.3	1,096.7	1,107.6	667.3	54.8		3,608.7
Total Program Support/Other	54.7	63.8	60.8	42.4	42.7	1.1	265.5
Unfunded Future Expenses/Risk Reduction Activities	-	83.3	16.4	22.2	75.6		197.5
Total Budget Requirements	805.0	1,243.8	1,184.8	731.9	173.1	1.1	4,139.7

*** CCtCap value only represents CCP portion which only includes a total of 2 PCM flights; remaining PCMs in ISS Budget**

- Three budget components
  - Cost of CCiCap and CCtCap contract milestones: contractual requirements NASA has committed to paying once companies successfully complete their milestones
  - NASA program office costs, including civil servant labor, travel, etc.
  - Unfunded Future Expenses: essentially reserves for special studies, additional tests, etc.
- If NASA does not receive funding sufficient to cover CCtCap costs, will have to adjust (delay) milestones for both partners proportionally
  - Partners may request contract cost adjustments, affecting certification dates

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Commercial Crew Program: FY 2015 – FY 2016 Plans

- CCDev2 milestones planned
  - Blue Origin
    - Flight demonstrations of BE-3 engine and subscale propellant tank assembly
    - Pusher escape in-flight escape demonstration data review
    - Agreement added three unfunded milestones, extended to April 2016
- Remaining CCiCap milestones planned
  - Sierra Nevada Corporation
    - Engineering test article flight test
  - SpaceX
    - Pad abort test
    - Dragon primary structure qualification (hatch open test)
    - Delta crew vehicle critical design review (CDR)
    - In-flight abort test

Blue Origin Crew Capsule after a successful suborbital test of the escape system in Texas.

Sierra Nevada Corporation Dream Chaser spacecraft sits on the runway at NASA Armstrong Flight Research Center in California.

Human Exploration and Operations

Commercial Crew Program: FY 2015 – FY 2016 Plans (continued)

- Sample CCtCap key milestones planned
  - Boeing
    - Certification Baseline Review (completed)
    - Ground Segment Critical Design Review (completed)
    - Delta Critical Design Review
    - Phase II Safety Review
    - Integrated parachute system drop tests
  - SpaceX
    - Certification Baseline Review (completed)
    - Delta Critical Design Review
    - Avionics test bed activation
    - Launch Site Operational Readiness Review
    - Space Suit Qualification Testing Complete

Astronaut Randy Bresnik enters Boeing CST-100 spacecraft for a fit check at the Houston Product Support Center.

The SpaceX Dragon pad abort test article undergoes final integrated testing prior to being shipped to Cape Canaveral Air Force Station in Florida for an upcoming pad abort test.

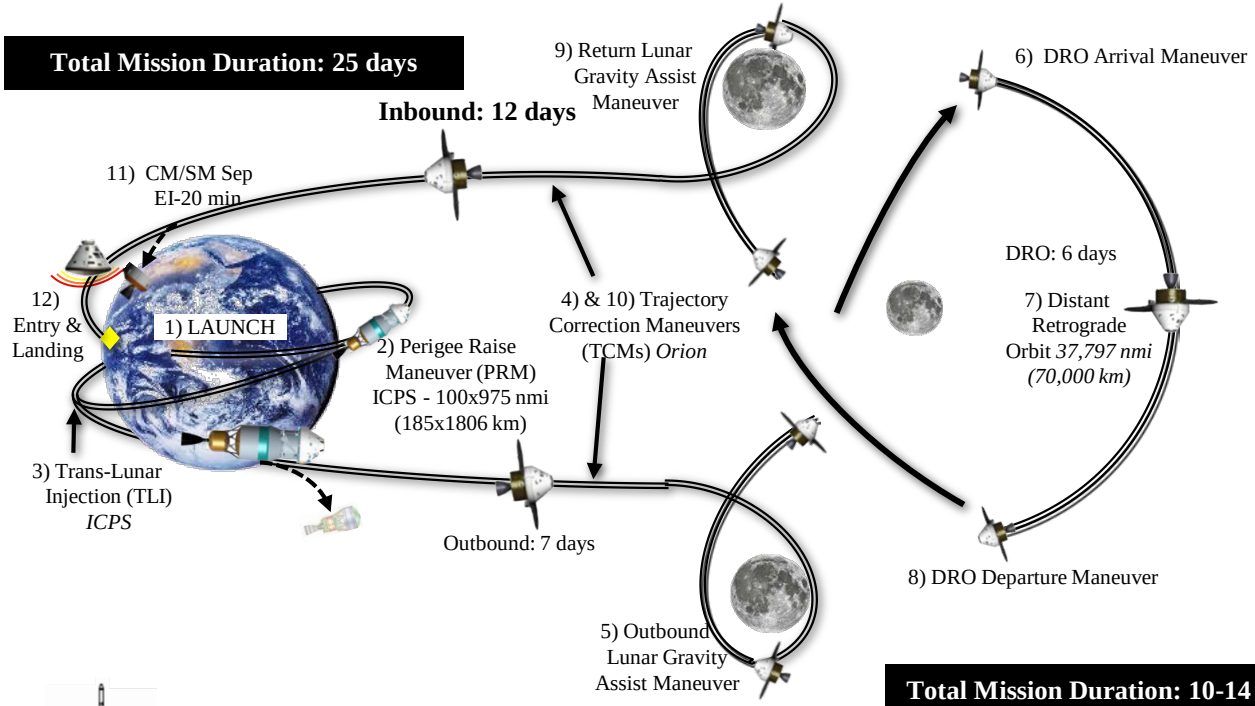
Exploration Systems Development

Orion
Space Launch System
Exploration Ground Systems

Human Exploration and Operations

Exploration Systems Development: Mission Overview

Total Mission Duration: 25 days



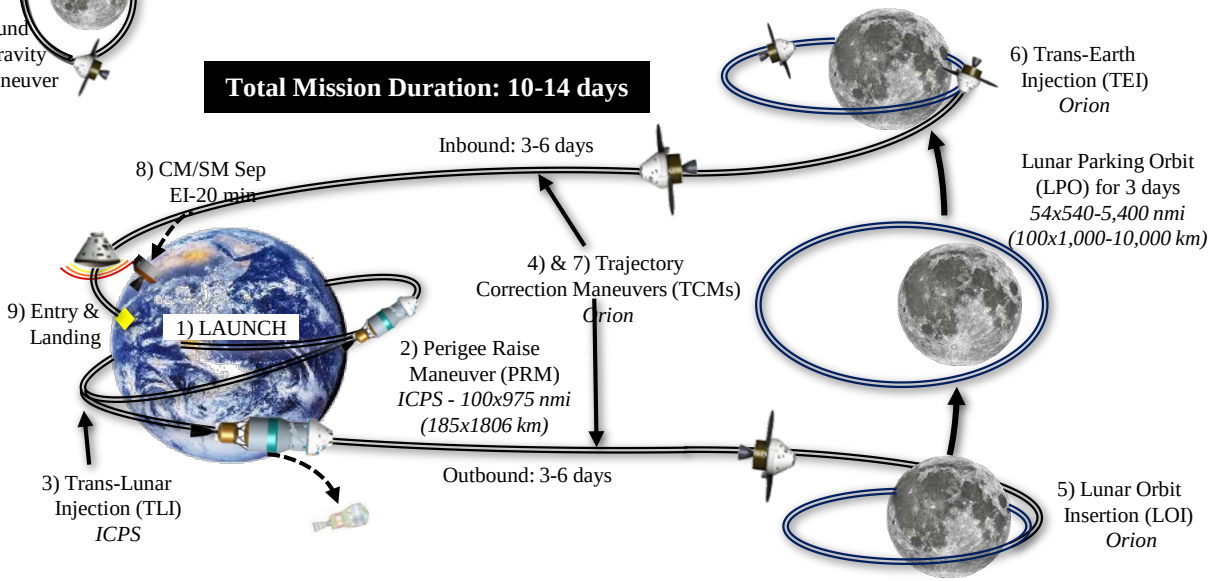
Flight 1 Mission Design
Uncrewed Distant Retrograde Orbit Mission

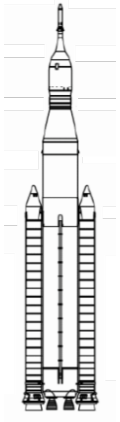
EM-1 Baseline Objectives:

- Demonstrate spacecraft systems performance prior to crewed flight
- Demonstrate high speed entry (~11 km/s) and TPS performance prior to crewed flight
- Landing off the coast of California

Flight 2 Mission Design
crewed Orion Lunar Orbit Flight in FY 2021-2022

Total Mission Duration: 10-14 days





EM-1/-2 SLS Configuration

- 5-seg SRBs and 4 RS-25D
- 22x975 nmi (40.7x1806 km) insertion orbit
- 28.5 deg inclination

EM-2 Objective (candidate):

- Demonstrate crewed flight beyond LEO

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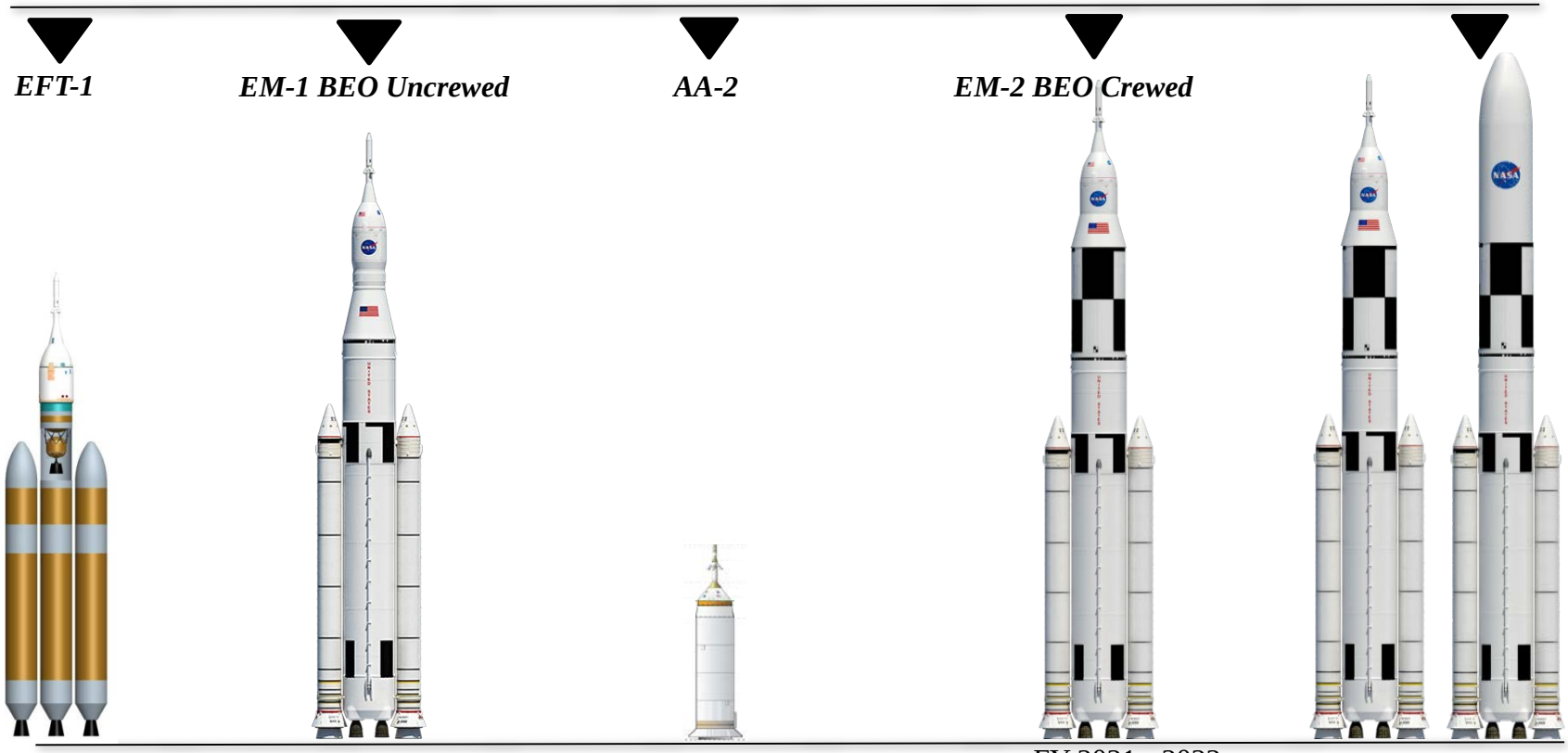
Exploration Systems Development: Integrated Manifest



Test Article - Orion
Commercial
Launch Vehicle
(flown December 5, 2014)

Uncrewed Orion
SLS - 70 mt
(Block I)
SLS (70% JCL) and EGS (80% JCL) for November 2018
(Integrated EM-1 launch date TBD by December 2015)

FY 2019
Launch Abort System
Test Article - Orion

FY 2021 - 2022
Crewed Orion
SLS – <105 mt with Exploration Upper Stage or ICPS
(EUS SRR/SDR in work)

(TBR)
Crewed Orion
SLS – 105 mt with Exploration Upper Stage
(crew or cargo variant)

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Exploration Systems Development:
Orion – Exploration Flight Test 1

- Launched Exploration Flight Test (EFT-1) on December 5, 2014 at 7:05 EST from Launch Complex 37 at Cape Canaveral Air Force Station
- Validated program design and manufacturing techniques as well as integration with SLS, EGS, and SCaN
- Fully met 85 of 87 flight test objectives (FTO), pending final spacecraft inspection and flight instrument/imagery data review
  - Partially met remaining two FTOs related to crew module uprighting system bag deployment
- Helped lower 13 of 17 top risk drivers for EM-2 loss of crew
  - Nominal performance with thermal protection systems, separation events, and parachute performance
- Achieved landing target within 1.5 nautical miles and 0.6 nautical miles at drogue parachute deployment – within the 5.4 nautical mile error circle requirement

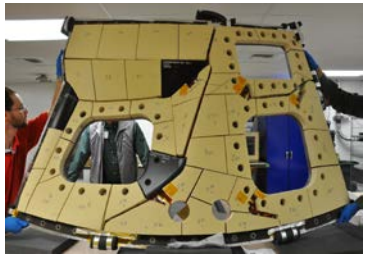
Orion rides into orbit atop a Delta IV Heavy launch vehicle during EFT-1.

A camera mounted on the spacecraft captures inflight separation of Orion service module jettison panels.

Human Exploration and Operations

Exploration Systems Development:
Orion – FY 2015 Plans

- Continue to analyze data collected from EFT-1
- Began component manufacturing for domestic portion of EM-1 service module in November 2014
- Completed wind tunnel testing on a subscale main parachute to provide risk mitigation options for EM-2 crewed flight in January
- Performed back shell abort acoustic test for EM-1 at Plum Brook; test completed in February
- Conducted launch abort system attitude control motor high thrust test to support EM-2 design in March
- Shipped EFT-1 heat shield from KSC to MSFC for additional post flight performance evaluation in March
- Complete heat shield trade studies and redesign to support lunar type reentry velocity Q3 FY 2015
- Complete structural component fabrication for EM-1 flight article and deliver to MAF for welding operations; first weld scheduled for June
- Complete Key Decision Point-C Review in Q3-Q4 FY 2015
- Complete EM-1 European Service Module (ESM) structure assembly at Thales Alenia Space in Italy, and begin structure installation on integration stand in September



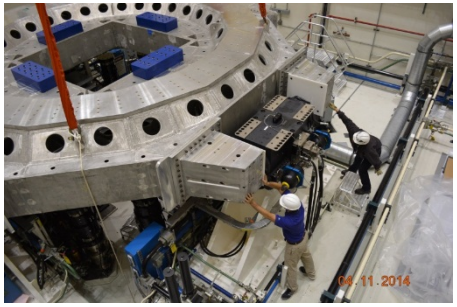
Technicians at GRC Plum Brook facility position the EM-1 back shell panel for an abort acoustic test.

Wind tunnel testing of Orion subscale main parachutes conducted at ARC.

Human Exploration and Operations

Exploration Systems Development:
Orion – FY 2016 Plans

- Complete program/European service module (ESM) CDRs in Q1
- Complete European structural test article (eSTA) structure assembly at Airbus, ship to Plum Brook to join domestic eSTA components in October
- Deliver NASA provided orbital maneuvering system engine for ESM integration by December
- Complete closeout weld of EM-1 flight article structure in October, deliver to KSC in January
- Complete EM-1 crew module proof pressure test at KSC in February
- Complete EM-1 ESM structure installation, begin integration in March
- Complete EM-1 crew module secondary structure installation in April
- Deliver EM-1 propulsion and ECLSS tubing to KSC, begin installation in April
- Begin Plum Brook eSTA testing in November, complete in April
- Begin LaRC water impact testing in April, complete in August
- Continue design and development engineering, begin EM-1 long lead procurements



Technicians tune the test table in the Mechanical Vibration Facility at GRC Plum Brook Station for eSTA testing.

An upgraded Orion test article will perform water impact testing in the Hydro Impact Basin at Langley Research Center.

Human Exploration and Operations

Exploration Systems Development:
Space Launch System – FY 2015 Plans

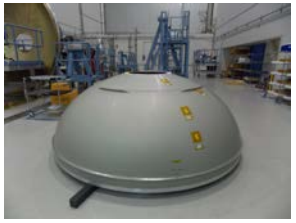
Core Stage	Complete certification and transfer of Vertical Assembly Center (VAC) – the last major SLS weld tool, and a critical milestone for production of structural test and flight hardware
Core Stage	Complete production of LOX tank, intertank, LH2 tank, and forward skirt structural test articles
Core Stage	Complete production of feedline hardware for EM-1 flight article
Engines	Completed first RS-25 core stage engine hot-fire test since 2009
Engines	Begin delivery of four RS-25 core stage engine controller units
Booster	Conduct first of two qualification motor tests
Booster	Begin casting of first EM-1 flight article motor segment
Adapters	Begin production of launch vehicle and Orion stage adapters for EM-1 flight article
ICPS*	Begin production of EM-1 flight article
ICPS	Deliver structural test article
SEI	Provide flight software releases 10 and 11; software integration test facility – qualification facility operational
Program	Complete critical design review

*ICPS – Interim Cryogenic Propulsion Stage


Vertical Assembly Center


Booster QM-1 Test Prep

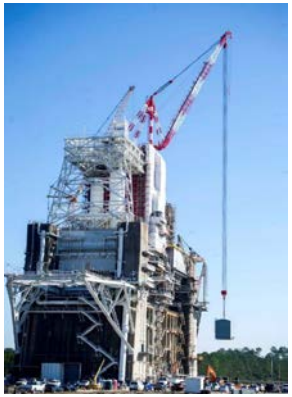

RS-25 Engine Test


ICPS STA LOX Dome

Human Exploration and Operations

Exploration Systems Development:
Space Launch System – FY 2016 Plans

Core Stage	Complete testing of LOX tank structural test article
Core Stage	Complete production of EM-1 flight article and ship from MAF to SSC for green run testing
Core Stage	Deliver four RS-25 core stage engines to MAF for integration in EM-1 flight article core stage
Engines	Complete qualification testing of RS-25 engine controller unit
Booster	Conduct second of two qualification motor tests
Booster	Continue casting of EM-1 flight article motor segments
Booster	Complete production of avionics, cables, line replacement units, batteries, and aft-skirt for EM-1 flight article boosters
Adapters	Complete production of launch vehicle stage adapter structural test article and begin integrated testing
SEI	Provide flight software releases 12 and 13 in support of core stage green run testing at SSC


B-2 Core Stage Test Stand


Core Stage Barge *Pegasus*


Booster Aft Skirt


RS-25 Flight Engines

Human Exploration and Operations

Exploration Systems Development:
Exploration Ground Systems – FY 2015 Plans

- Complete EFT-1 Orion landing and recovery operations
- Complete structural and facility modifications; begin ground support equipment installation for mobile launcher
- Continue adjustable high bay access platform construction in Vehicle Assembly Building (VAB)
  - Provides access levels required for SLS vehicle processing
- Awarded Launch Complex 39-B flame trench/deflector contract on February 3, 2015; two protests filed which will delay construction; complete construction of ignition overpressure and sound suppression systems
  - Allows launch pad to absorb acoustic launch environment generated by SLS
- Continue upgrades and modifications for crawler-transporter to complete installation of roller bearings, jacking, equalizing and leveling (JEL) cylinders
  - Provides stability to launch vehicle for rollout from VAB to launch pad
- Begin installing applications and displays in several processing facilities
  - Establishes command and control capability in majority of ground processing facilities required for SLS and Orion

Human Exploration and Operations

Exploration Systems Development:
Exploration Ground Systems – FY 2016 Plans

- Complete Critical Design Review to evaluate ground systems design integrity and ability to meet mission requirements
- Conclude ground support equipment installation for mobile launcher
- Conduct launch equipment test facility umbilical testing
- Complete crawler-transporter JEL cylinder installation
- Complete adjustable high bay platform construction in VAB to support SLS stacking and integration for EM-1
- Complete flame trench/flame deflector as well as modifications for infrastructure and propellant and gas systems in preparation for launch at Launch Complex 39B
- Begin test of command, control, and communications systems software and displays that support end-to-end spaceport applications to support launch

Exploration Research and Development

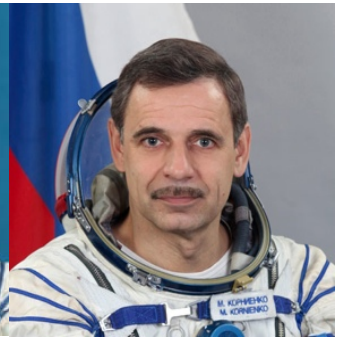
Human Research Program
Advanced Exploration Systems
Asteroid Redirect Mission

Human Exploration and Operations

Human Research Program: FY 2015 Plans

- FY 2015 marks launch of astronaut Scott Kelly and cosmonaut Mikhail Kornienko to ISS for a year long mission – the longest ever assigned to a US astronaut
  - HRP and Russian partners developed joint biomedical research plan that includes subject, hardware, and data sharing
  - Mission incorporates a unique study of identical twins astronaut Scott Kelly, and retired astronaut, Mark Kelly
  - From across the nation, NASA formed pioneering team of leading genetics and genome experts to explore effects and changes that may occur in spaceflight (as compared to Earth) by studying two individuals with the same genetics, but are in different environments, for one year
  - For more information see
    - http://www.nasa.gov/content/one-year-mission
    - http://www.nasa.gov/content/twins-study/

Scott Kelly
STS-103, STS-118,
ISS 25/26



Mikhail Kornienko
ISS 23/24

Astronaut Scott Kelly, who will spend a year on ISS, and his twin brother, retired astronaut Mark Kelly.

Human Exploration and Operations

Human Research Program: FY 2016 Plans

- Conclude one year joint US/Russian ISS mission
  - NASA will obtain full year of mission data on ocular health, immune and cardiovascular systems, cognitive performance testing, and countermeasure effectiveness against bone and muscle loss
  - Identical twin study findings will provide new "omics" data to study effects of spaceflight on entire complement of biomolecules, such as proteins (proteomics), genes (genomics), etc.
- Conduct additional studies to mitigate long duration spaceflight risk including
  - Lighting countermeasure to help crewmembers improve sleep and enhance performance
  - Ultrasound tool to monitor changes in spine
  - A new hand held focused ultrasound, developed by University of Washington and NSBRI, will improve kidney stone detection and provide treatment by moving the stone using ultrasonic propulsion
    - This technology could change kidney stone treatment on Earth, enabling stone detection and removal during initial office visit

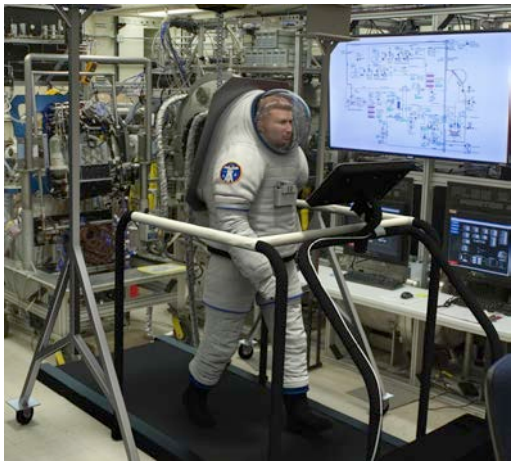
Astronauts Luca Parmitano and Chris Cassidy collect fundoscope images of the eye for the ocular health experiment, investigating increased intracranial pressure.

Astronaut Janet Kavandi wears the Actiwatch to record activities as part of crew sleep-wake patterns investigation.

Human Exploration and Operations

Advanced Exploration Systems: FY 2015 Plans

- Advance space suit components for future exploration requirements
  - Complete next generation portable life support system (PLSS 2.0) and modify advanced crew escape suit (MACES) pressure garments
  - Complete human-in-the-loop PLSS 2.0 testing, and prototype exploration suit and MACES garments
  - Conduct interim design review and begin procurement of components for next iteration of PLSS 2.5
- Continue public-private lunar lander partnerships under Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) initiative awards:
  - Tethered flight tests of Moon Express lander
  - End-to-end mission simulation for Astrobotic lander
  - Preliminary Design Review for Masten Space Systems lander propulsion system
- Support Lunar activities including RESOLVE, Lander Technology, and Lunar Flashlight



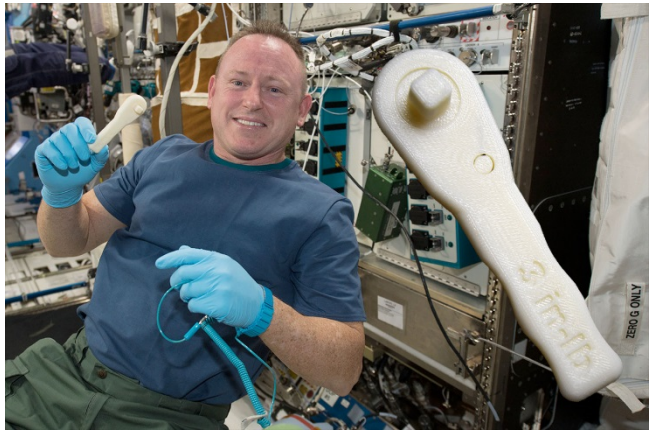
Artist rendering of engineers performing human-in-the-loop testing of extravehicular activity portable life support system.

The Moon Express lander undergoes a tethered flight test at Kennedy Space Center in Florida.

Human Exploration and Operations

Advanced Exploration Systems: FY 2015 Plans (continued)

- Maintain investments for in-space manufacturing technology development and demonstration on ISS
  - Develop and test 3D printing processes for metallic parts, laser scanners to measure dimensions of 3D printed parts, and systems to recycle discarded plastic to produce feedstock for 3D printers
- Bigelow Expandable Activity Module (BEAM) scheduled to arrive at ISS aboard SpaceX-8 cargo resupply mission
  - BEAM will attach to ISS (node 3 aft) to test inflatable structures technology that could be used for deep space habitat on human missions to Mars
- Continue Joint Robotics Precursor Activities with Science Mission Directorate
  - Complete Preliminary Design Reviews for payloads on Mars 2020 mission to demonstrate oxygen production from Mars atmosphere, and measure surface weather conditions
  - Fully engage Solar System Exploration Research Virtual Institute with research studies



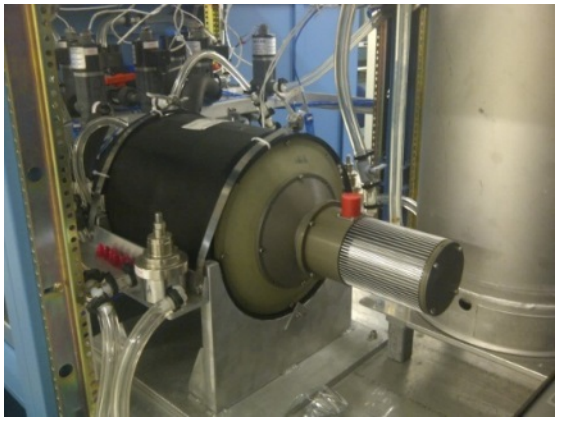
Astronaut Butch Wilmore shows off a new ratchet wrench – the first tool fabricated with a 3D printer on the International Space Station.

BEAM prototype on display at Johnson Space Center in Texas.

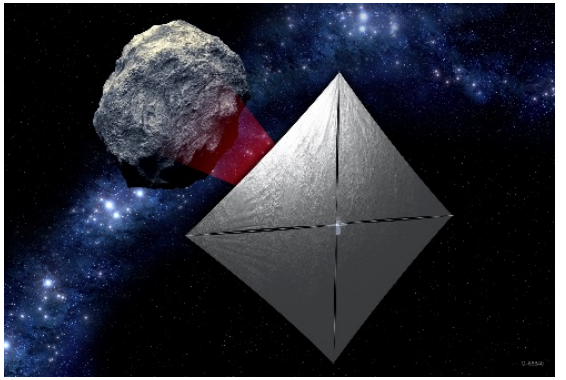
Human Exploration and Operations

Advanced Exploration Systems: FY 2015 Plans (continued)

- Complete design reviews for three life support systems to demonstrate on ISS: high-pressure oxygen supply, micro total atmosphere monitor, cascade distillation subsystem
- Continue operations of radiation sensor on Mars Curiosity, complete data analysis of radiation sensor payload flown on EFT-1, next mission planned for EM-1, finalize accommodation arrangements with Orion
- Demonstrate advance caution and warning system on EFT-1 to detect and diagnose faults in Orion power system (completed December 2014)
- Complete selection of NextSTEP Broad Area Announcement (BAA) awards in advanced in-space propulsion, habitation, and secondary payloads on EM-1
- Complete risk reduction on EM-1 secondary solar sails



The cascade distillation subsystem for wastewater recycling undergoes testing in the Advanced Water Recovery Systems Development Facility at Johnson Space Center.



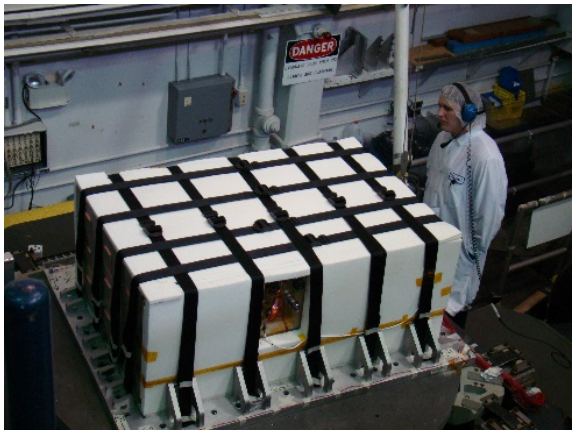
The Near-Earth Asteroid Scout mission will use a solar sail to fly by asteroids and characterize potential targets for human exploration.

Human Exploration and Operations

Advanced Exploration Systems: FY 2016 Plans

- Mature integrated space suit exploration capability leading to flight demonstration in 2021/2022
  - Perform human vacuum evaluation of Z-2 space suit pressure garment with follow-on underwater testing
  - Complete PLSS 2.5 assembly
    - Start developing initial kits (interface with Orion/communications kit) for EVAs in proving ground
- Integrate sensors and feedback controls with ISS-derived air revitalization subsystem to increase performance and reliability
- Launch first of three Spacecraft Fire Safety experiments (Saffire-1) on Orbital (planned for Orb-5, Orb-6, Orb-7)
  - Saffire tests will increase knowledge of risk, detection, suppression, and clean up related to fire safety in space
  - After initial three tests complete, experiments will continue, with each building upon previous data to move through entire fire detection, suppression, and post-fire clean up phases

Z-2 Space Suit garment under development at Johnson Space Center.



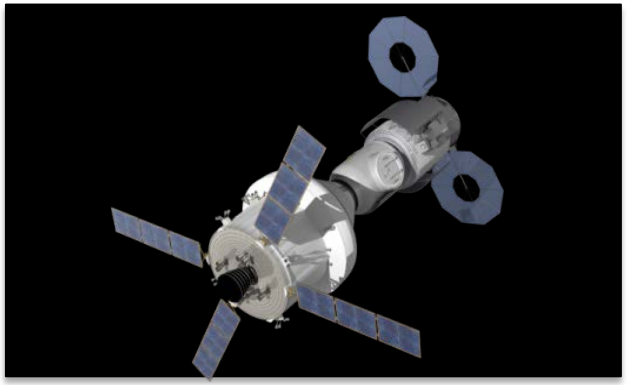
The Saffire-1 spacecraft fire safety experiment undergoes vibration testing at Glenn Research Center in Ohio.

Human Exploration and Operations

Advanced Exploration Systems: FY 2016 Plans (continued)

- Complete environmental testing of commercial lunar lander by Lunar CATALYST partner, Astrobotic Technologies
- Complete Systems Requirement Review for Resource Prospector launch in 2020 to search for water on the Moon
- Conduct ground tests of advanced in-space propulsion technologies to reduce travel time to Mars, including high-power electric propulsion systems selected via NextSTEP BAA
- Begin Phase II development of deep space habitat concepts with commercial partners selected via NextSTEP BAA

Astrobotic Technologies car-sized “Griffin” lunar lander may one day provide affordable lunar access for exploration, science, and resource utilization.

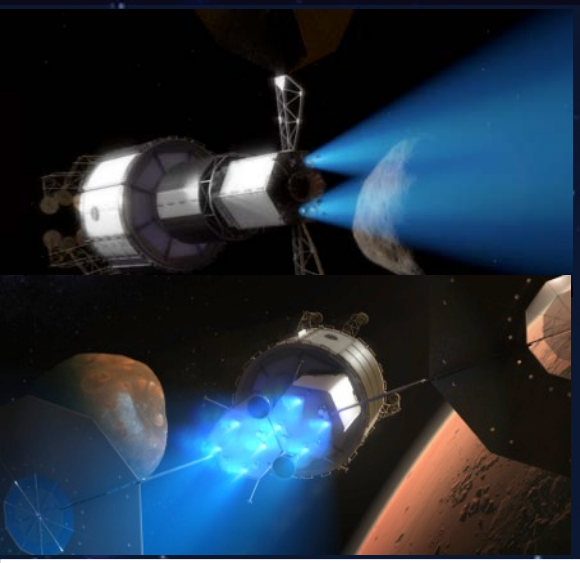


Beyond Earth orbit deep space habitat concept that will dock with Orion to extend mission capabilities.

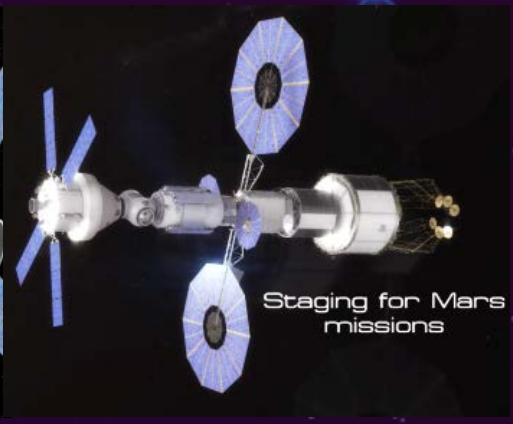
Asteroid Redirect Mission

Human Exploration and Operations

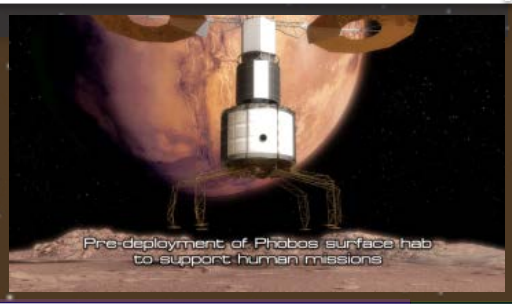
Asteroid Redirect Mission:
Risk Reduction for Future Mars and Deep Space Missions



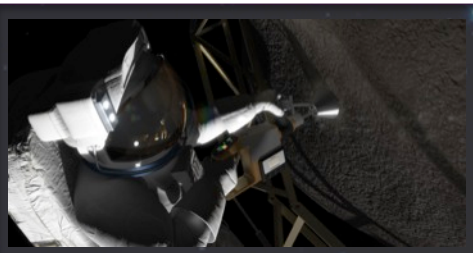
Long duration **human-scale systems operating in deep space**. Pre-deployment of crewed mission elements via solar electric propulsion with long quiescent periods.

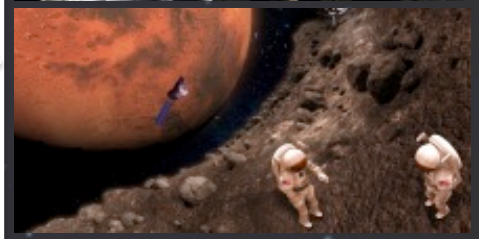


Sensor suites and proximity operations required for aggregating Mars mission vehicle stacks, deep space rendezvous and docking with Orion.

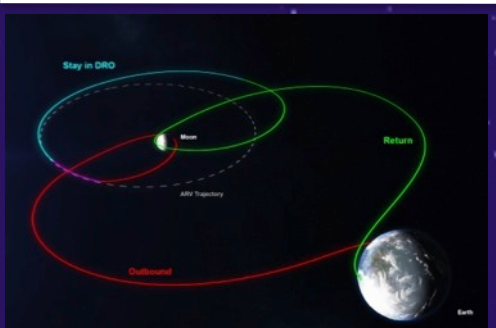


Enhanced interaction with **uncooperative, low-G targets** as will be experienced with Mars Moons.





In-space EVA ops and on micro-g body (Phobos), sample handling, and ISRU.



Mission Operations: Deep space trajectories, rendezvous and docking, pre-deployment of systems.

Long duration, high-power **Solar Electric Propulsion:** Solar arrays, thrusters, PMAD, Xenon storage.

Human Exploration and Operations

Asteroid Redirect Mission: FY 2015 Plans

- Continue essential activities that can be utilized on ARM
  - Begin long lead component technology procurements for SEP technology demonstration mission (STMD)
  - Robotic systems and controls for interaction with non-cooperative bodies (HEO/ISS)
  - Advanced EVA technology maturation (HEO/AES)
- Continue internal and study contract risk reduction and concept development for integrated mission
- Selected robotic mission capture system Option B to extract a boulder from a larger asteroid
- Completed robotic Mission Concept Review that included an independent NASA technical and cost assessment for proposed mission concept

Human Exploration and Operations

Asteroid Redirect Mission: FY 2016 Plans

- Continue essential ongoing activities that can be utilized on ARM
  - Continue asteroid observations (SMD)
  - Continue SEP technology demonstration activities (STMD)
  - Satellite servicing autonomy, controls, and robotic manipulators (HEO/ISS)
  - Advanced EVA technology maturation (HEO/AES)
  - Complete development of integrated robotic mission requirements
  - Begin long lead procurement activities related to the spacecraft bus or SEP module and capture module
  - Continue mission concept development, including partnerships, for a crewed mission planned for mid-2020's

Human Exploration and Operations

Asteroid Redirect Mission: Budget Profile

- Established new line item under AES beginning in FY 2016 to continue to formulate the integrated demonstration mission and align key technologies and capabilities for future exploration missions

NOA $M	**FY 2015***	**FY 2016**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**
ARM *(includes Robotic and Crewed mission)*		38	40	141	300	400
Leveraged Content:						
SEP (STMD)	36	69	67	45	5	0
EVA/ISRS (HEO)	43	56	33	22	17	15

Excludes launch vehicle

* FY 2015 reflects the Agency Initial Operating Plan.

Space and Flight Support

Space Communications and Navigation
Launch Services Program
Rocket Propulsion Testing
Human Space Flight Operations
21st Century Space Launch Complex

Human Exploration and Operations

Space Communications and Navigation: FY 2015 and FY 2016 Plans

- FY 2015 plans
  - Continue software coding, hardware integration and testing for SGSS
  - Achieve operational capability of 34 meter antenna DSS-35 at Canberra, Australia
  - Finish TDRS-M and place into storage
- FY 2016 plans
  - Continue software coding, hardware integration and test for SGSS; begin system deployment and transition activities at White Sands Complex
  - Complete delivery of second 34 meter antenna DSS-36 at Canberra, Australia
  - Continue SGSS system Integration and Test

Human Exploration and Operations

Rocket Propulsion Testing: FY 2015 Plans

- Stennis Space Center
  - Perform 8 tests of RS-25 engine to support SLS and continue refurbishing B-2 test stand to prepare for SLS core stage testing
  - Continue developmental testing of commercial engine systems on reimbursable basis
  - Replace A and B legs of high-pressure industrial water system, repair liquid oxygen and liquid hydrogen barges, and upgrade high-pressure gas facility
  - Begin replacement of E Test Complex data acquisition system to support test of sub-scale and component assemblies and engines
- White Sands Test Facility
  - Perform testing for DoD Missile Defense Agency and US Air Force
  - Prepare for testing Boeing commercial crew service module (on a reimbursable basis) and European Space Agency Orion service module
  - Begin refurbishment activities for large altitude simulation system
- Marshall Space Flight Center
  - Continue testing of rocket engine components using select laser melting and other additive manufacturing processes
- Glenn Research Center Plum Brook Station
  - Incorporate 30,000-gallon liquid hydrogen tank into system to support testing components that require liquid hydrogen (LH2) and liquid oxygen (LOx)
  - Perform facility repairs and refurbishment for 11-foot vacuum isolation valve enabling electric propulsion testing utilizing cryogenic cooling panels, and LH2/LOx engine hot fire testing

Human Exploration and Operations

Rocket Propulsion Testing: FY 2016 Plans

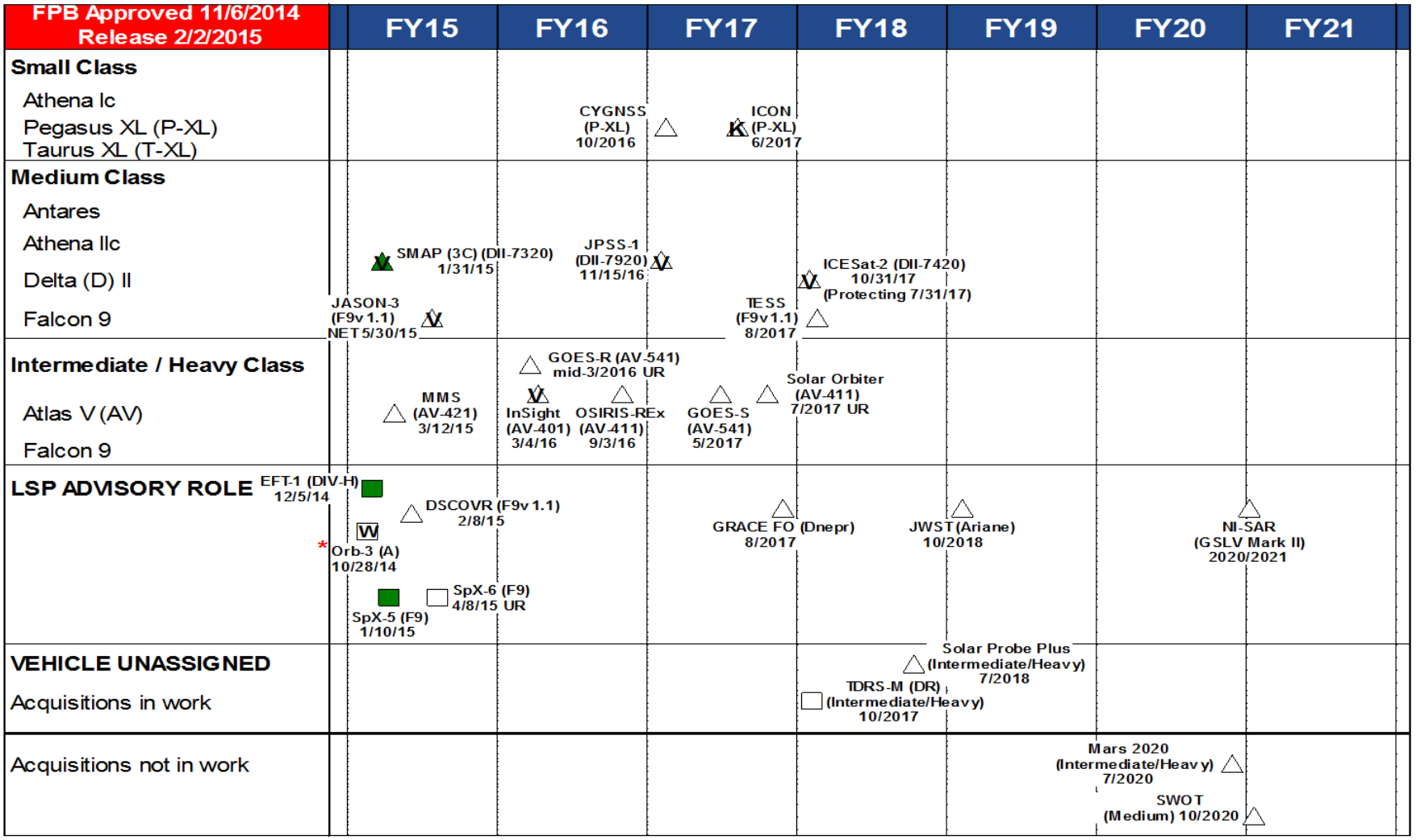
- Stennis Space Center
  - Perform engine testing for Aerojet Rocketdyne RS-68 engine, SpaceX and other commercial engine developers that support future ISS resupply requirements
  - Perform 13 tests of RS-25 engine in support of SLS on A-1 test stand at SSC
  - Activate B-2 test stand at SSC to prepare for SLS integrated engine testing

The RS-25 engine that will power the Space Launch System rocket, shown during its first test at the Stennis Space Center A-1 test stand in Mississippi.

- White Sands Test Facility
  - Finalize preparations for Orion ESA Service Module at WSTF
  - Prepare required test facilities to support Orion ESA service module and Boeing CST-100 service module; testing planned for FY 2017
  - Continue testing advanced rocket propulsion design and manufacturing techniques for government and commercial propulsion system developers
  - Refurbish large altitude simulation system at WSTF, which supports future space environment testing for Boeing commercial crew vehicle, Missile Defense Agency and US Air Force test articles
  - Perform engine testing for US Air Force and commercial engine developers that support future ISS resupply requirements

Human Exploration and Operations

Launch Services Program: Manifest



* * * *

△ = SCIENCE ◇ = DOD REIMBURSABLE

□ = HUMAN EXPLORATION AND OPERATIONS

For NASA Planning Purposes Only

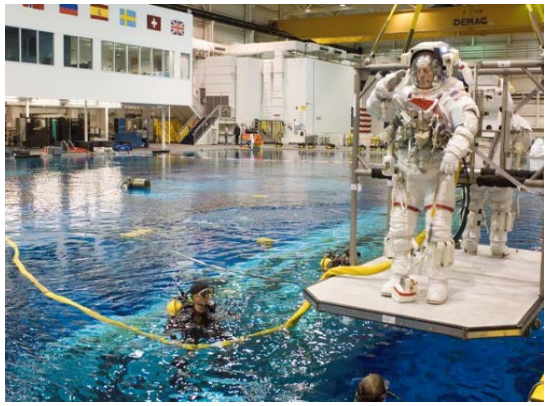
* * * *

C = CubeSat	V = Vandenberg Air Force Base	* = MISSION UNSUCCESSFUL	LSTO in Work = L
K = KWAJALEIN	W = Wallops	UR = UNDER REVIEW	Draft RLSP in Work = DR

Human Exploration and Operations

Space Flight Crew Operations: FY 2015 and FY 2016 Plans

Crewmembers transfer frozen science samples aboard ISS from minus eighty-degree lab freezer to a portable double cold bag for return to Earth.



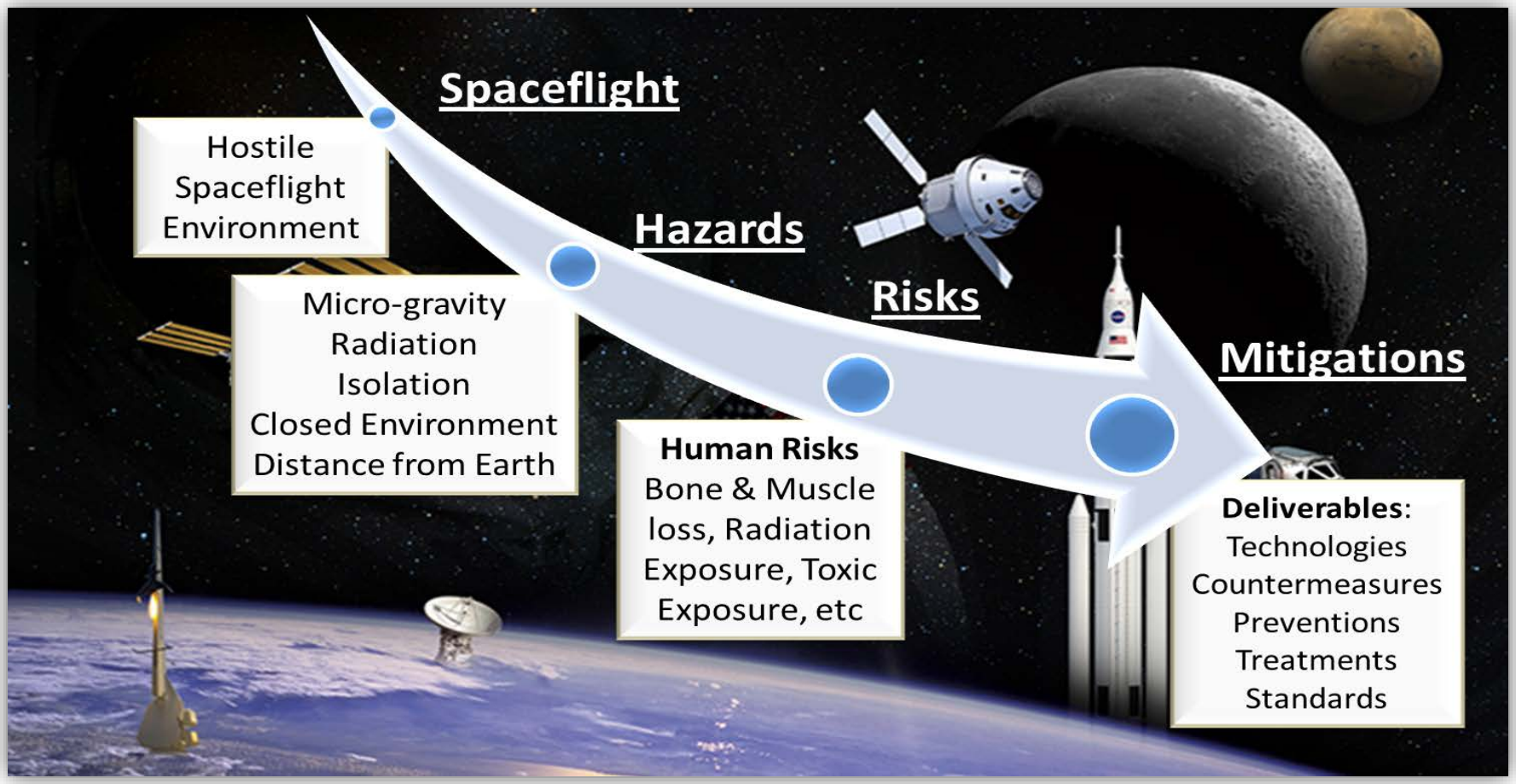
Astronauts train in the Neutral Buoyancy Lab at Johnson Space Center, in preparation for extravehicular activity operations.

- Manage NASA human space flight efforts, including directing and managing flight crew activities, astronaut selection, training astronaut candidates, and deployment and return of flight crews from Russia
- FY 2015 plans
  - Evaluate and promote improved design for next generation ascent/entry and EVA space suits, including block Extravehicular Mobility Unit upgrade, to reduce injury and accommodate greater anthropometric range
- FY 2016 plans
  - Begin commercial crew training for missions to ISS
  - Interview and select astronaut candidate to align with manifest support requirements

Human Exploration and Operations

Crew Health and Safety:
Astronaut Occupational Surveillance Activity

Program based on spaceflight hazards and associated human risk; surveillance tasks and mitigation development are result of partnering efforts including International Space Station, Human Research Program, Advanced Exploration Systems and Crew Health and Safety



Human Exploration and Operations

Crew Health and Safety: FY 2015 and FY 2016 Plans

- FY 2015 plans
  - Provide clinical certification and mission support for active astronauts
  - Provide physical, behavioral, and reconditioning health support for returning ISS expeditions
  - Develop and implement one year mission unique surveillance standard measures; mission launched March 27, 2015
  - Standardize data collection of space suit exposure during crew training
  - Provide support to Chief Health and Medical Officer on Institute of Medicine report; aimed at long-term improvement in crew member occupational health and maintenance
- FY 2016 plans
  - Support ISS one year crew
    - Provide real time on-orbit health monitoring, exercise regimen management, and behavioral support
    - Provide post landing health evaluations, reconditioning and monitoring
  - Provide physical, behavioral, and reconditioning health support for returning ISS expeditions

Human Exploration and Operations

21st Century Space Launch Complex: Kennedy Space Center

- FY 2015 Plans
  - Continue to modernize and upgrade Telemetry System IV and Jonathan Dickinson Missile Tracking Annex range assets to enable higher flight vehicle data rate use
  - Develop cost effective systems for fault detection and isolation of ground support equipment, flight hardware and facility systems
  - Modernize offline processing facilities and ground servicing equipment
  - Continue Eastern Range Lightning System upgrade
- FY 2016 Plans
  - Complete replacement of old, deteriorating cable ducts that provide critical communications connection between KSC and Eastern Range
  - Begin facility design for eventual replacement/upgrade of converter compressor facility, which supplies gaseous nitrogen and helium to processing and launch sites across Florida Range
  - Complete Eastern Range Lightning System upgrade
  - Complete range telemetry upgrades and advanced ground system maintenance
  - Complete integrated health monitoring capabilities demonstration on real world systems through collaboration with development team

Human Exploration and Operations

21st Century Space Launch Complex: Wallops Flight Facility

- FY 2015 Plans
  - Continue construction of addition to building X-75 at Wallops Flight Facility (WFF) to provide elevated and protected housing for critical Island communications systems
  - Begin relocation of Pad 1 rail launcher and flat pad to mitigate risk of damage and schedule delays to ISS
  - Begin Range Control Center expansion and upgrades, Bermuda modernization study, and other work to support maintenance gaps at Wallops
  - Upgrade and improve access roads, utility systems, launch pad concrete base, and associated infrastructure
  - Replace existing electrical feeder and install conduit and feeder to provide reliable power to northern areas including the Payload Processing Facility
  - Start installation of fiber optic conduit system to facilitate future fiber requirements
- FY 2016 Plans
  - Complete relocation of Pad 1 rail launcher and flat pad at WFF
  - Finish repairs and modifications to building X-75 at WFF to provide elevated and protected housing for critical Island communications systems
  - Finish replacement of Island primary electrical feeder to provide reliable power to northern WFF areas including Payload Processing Facility