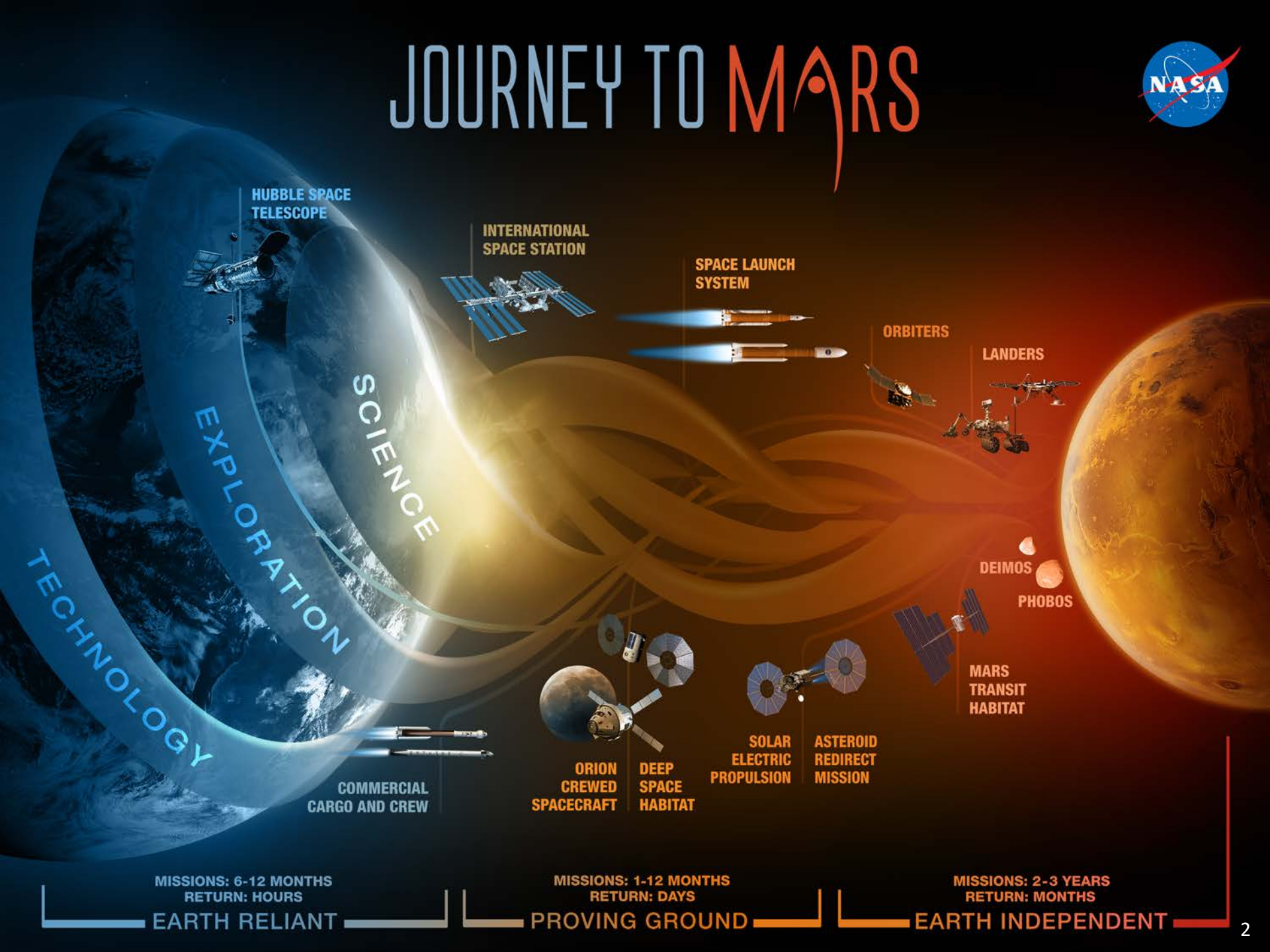
National Aeronautics and Space Administration

Advanced Exploration Systems: FY16 Activities

March 29, 2016

Chris Moore


JOURNEY TO MARS
NASA
HUBBLE SPACE TELESCOPE
INTERNATIONAL SPACE STATION
SPACE LAUNCH SYSTEM
ORBITERS
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

Capability Development Risk Reduction

Plan/resources understood
Plan/resources finalization required

	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	

Advanced Exploration Systems

Rapid development and testing of prototype systems and validation of operational concepts to reduce risk and cost of future exploration missions:

- **Crew Mobility Systems**
  - Systems to enable the crew to conduct “hands-on” surface exploration and in-space operations, including advanced space suits, portable life support systems, and EVA tools.
- **Habitation Systems**
  - Systems to enable the crew to live and work safely in deep space, including beyond earth orbit habitats, reliable life support systems, radiation protection, fire safety, and logistics reduction.
- **Vehicle Systems**
  - Systems to enable human and robotic exploration vehicles, including advanced in-space propulsion, extensible lander technology, modular power systems, and automated propellant loading on the ground and on planetary surfaces.
- **Foundational Systems**
  - Systems to enable more efficient mission and ground operations and those that allow for more Earth independence, including autonomous mission operations, avionics and software, in-situ resource utilization, in-space manufacturing, synthetic biology, and communication technologies.
- **Robotic Precursor Activities**
  - Robotic missions and payloads to acquire strategic knowledge on potential destinations for human exploration to inform systems development, including prospecting for lunar ice, characterizing the Mars surface radiation environment, radar imaging of NEAs, instrument development, and research and analysis.
- **Strategic Operations, Integration, and Studies**
  - Responsible for the management oversight of the HEO architecture and strategic planning, including mission and systems analysis and international coordination. Conduct studies and analyses to translate strategy into developmental (technology and capability) priorities and operational efficiencies.

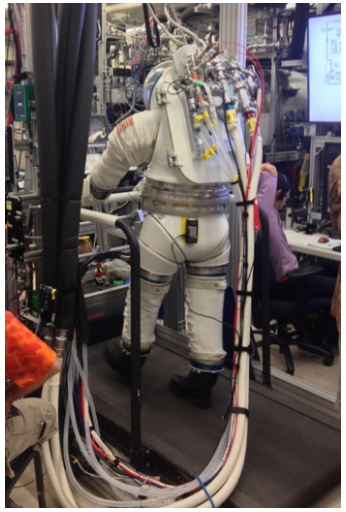
FY16 Summary

- In FY16, AES has established 65 milestones.
- Goal is to achieve at least 80%. Completed 78% in FY15.
- AES includes 460 civil servants and 154 contractors in FY16

Advanced Space Suit

- **Objectives**
  - Enable the crew to conduct “hands-on” surface exploration and in-space operations.
  - Demonstrate advanced space suit on ISS.
- **Portable Life Support System (PLSS)**
  - Developing next generation PLSS with new technology components for carbon dioxide removal, pressure regulation, thermal control, and energy storage.
  - Conducted human-in-the-loop testing.
- **Z-Suit**
  - Developing advanced space suit with improved mobility, duration, reliability and maintainability for surface exploration.
- **FY16 Activities**
  - Conduct electrical live loads test with PLSS 2.5 components.
  - Working with ISS Program to develop an integrated EVA strategy for demonstration of advanced suit on ISS.

PLSS 2.0



Human-in-the-loop testing of PLSS 2.0

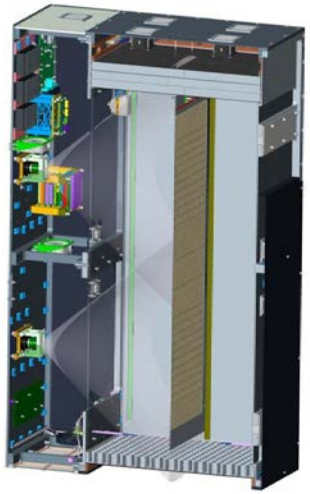
Z-2 suit

Spacecraft Fire Safety

- Saffire-1 is the first in a series of six fire safety experiments developed by GRC that will investigate the spread of large-scale fires in microgravity, and demonstrate technologies for combustion products monitoring and post-fire cleanup.

- Saffire-1 was launched on OA-6 (March 22, 2016). Saffire-2 and Saffire-3 are scheduled for OA-5 (June 2016) and OA-7 (October 2016).

- Saffire-1 will be activated on May 20 after Cygnus departs from ISS and before reentry.



Saffire-1 experiment

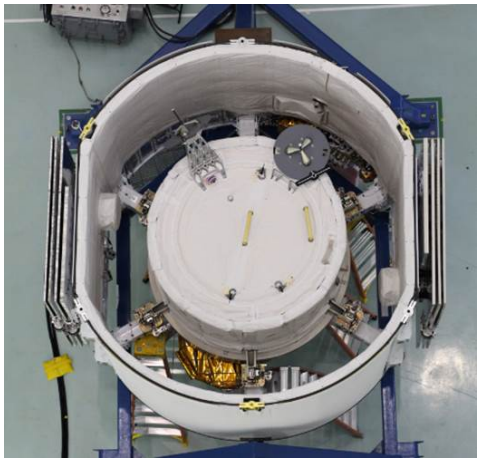
Saffire-1 after installation in Cygnus module

BEAM

- The Bigelow Expandable Activity Module (BEAM) is a public-private partnership to demonstrate a commercial inflatable module on ISS.
- BEAM is scheduled for launch on the SpaceX-8 mission on April 8.
- During its two-year mission, sensors inside BEAM will verify its structural integrity and characterize the radiation environment.

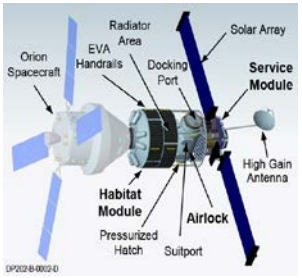
BEAM being installed in Dragon trunk

BEAM attached tp ISS



BEAM integrated with Dragon trunk

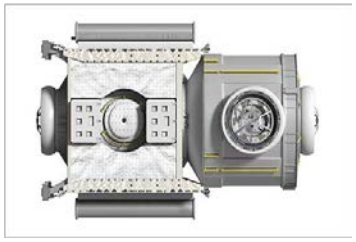
NextSTEP Phase 1 Habitation Studies



- **Lockheed Martin:** Habitat to augment Orion's capabilities. Design will draw strongly on LM and partner Thales Alenia's heritage designs in habitation and propulsion.

- **Bigelow Aerospace:** The B330 for deep-space habitation will support operations/missions in LEO, DRO, and beyond cis-lunar space

- **Orbital ATK:** Habitat that employs a modular, building block approach that leverages the Cygnus spacecraft to expand cis-lunar and long duration deep space transit habitation capabilities and technologies**.**

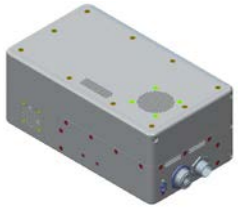


- **Boeing:** Developing a simple, low cost Exploration Augmentation Module (EAM) that is affordable early on, that allows various technologies to be tested over time, and that is capable of evolving into a long-duration crew support system for cis-lunar and Mars exploration.

ECLSS Flight Demos on ISS Currently in Development

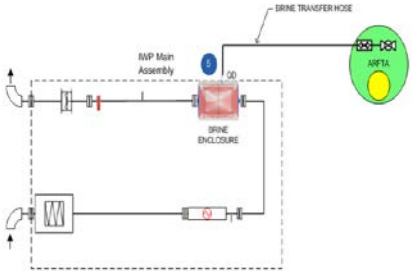
- **Long Duration Sorbent Test Bed:** Demonstration of improved sorbents for CO2 removal (Feb. 2016)

- **Organic Water Monitor:** Demonstration of instrument for measuring organic contaminants in ISS water system (Apr. 2016)



- **Aerosol Sampler:** Demonstration of modified COTS Aerosol Sampler on ISS to gather quantitative data on ambient air quality (Apr. 2016)

- **Brine Processor:** Demonstration of the Ionomer Membrane Water Processor to purify and recover 86% of the available water from brine (Dec. 2017)



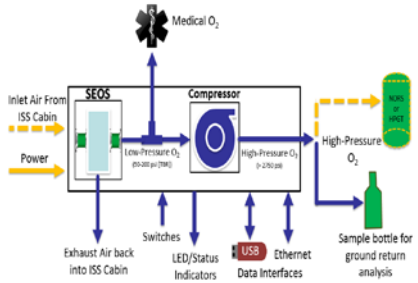
- **Spacecraft Atmosphere Monitor:** Demonstration of miniature mass spectrometer for detecting trace gas contaminants in ISS air (Feb. 2018)

ECLSS Flight Demos on ISS Currently in Development

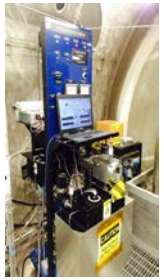
- **Universal Waste Management System:** Demonstration of common compact toilet for ISS and Orion (Oct. 2018)

- **Primary Watewater Processor:** Demonstrate Cascade Distillation System for wastewater processing (Feb. 2019)

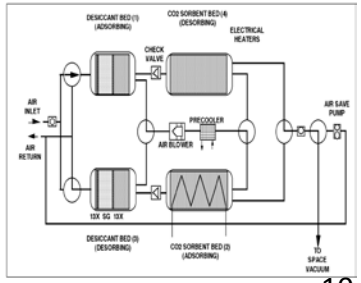
- **High Pressure High Purity Oxygen Generation:** Demonstration of a High Pressure/High Purity Oxygen generation system to support future EVA and emergency medical needs (Sep. 2019)



- **Oxygen Recovery:** Demonstration of Plasma Pyrolysis Assembly to convert up to 90% of the oxygen from carbon dioxide. (Oct. 2019)



- **CO2 Removal:** Demonstration of the next generation CO2 removal system that can operate for extended durations without maintenance. (Sep. 2021)



Radiation Sensors

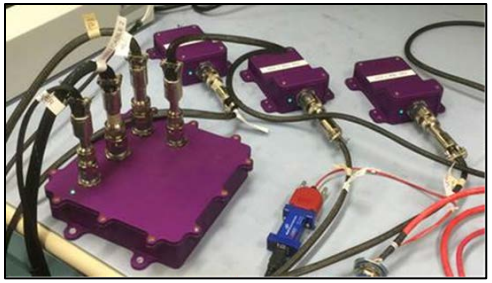
- Objectives:
  - Develop advanced radiation sensors to characterize the radiation environments of potential destinations for human exploration.
  - Update and validate radiation transport models with flight data.

- Flew Radiation Environment Monitors on EFT-1 and ISS. Providing radiation sensors for BEAM and BioSentinel.

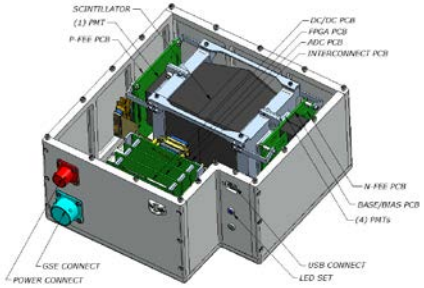
- Developing Hybrid Electronic Radiation Assessor (HERA) for flight on Orion during EM–1. Completed CDR.

- Developing Advanced Neutron Spectrometer for ISS flight demonstration in 2016. Calibrated spectrometer with particle beam testing and flight on high altitude balloon.

- Continuing operations of the Radiation Assessment Detector (RAD) on the Curiosity rover to characterize the Mars surface radiation environment.

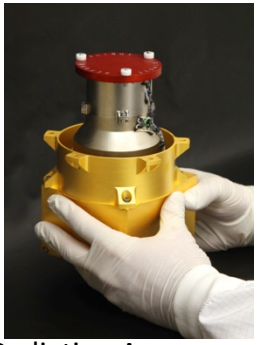


HERA



Fast Neutron Spectrometer Assembly with Top Plate removed

Advanced Neutron Spectrometer



Radiation Assessment Detector

Logistics Reduction

- ISS crew demonstrated extended wear clothing to reduce the mass of laundry on long missions.
- Delivered an acoustic Multi-Purpose Cargo Transfer Bag (MCTB) for demonstration on ISS. After being used to carry supplies to the ISS, the MCTB will be repurposed to provide acoustic insulation. The MCTB will be attached to the walls of the crew quarters to reduce the noise from the treadmill. The MCTB was launched on the Orb-4 cargo resupply mission in early December.
- Developing Radio Frequency Identification (RFID) tag readers to be installed in ISS hatchways to autonomously track movement of inventory. Mobile readers will also be carried on the next generation free flyer robot (Astrobee) being developed by STMD
- Awarded contract to Hamilton Sundstrand Space Systems for development of Universal Waste Management System (UWMS). The UWMS will be tested on ISS and serve as the flight system for Orion.

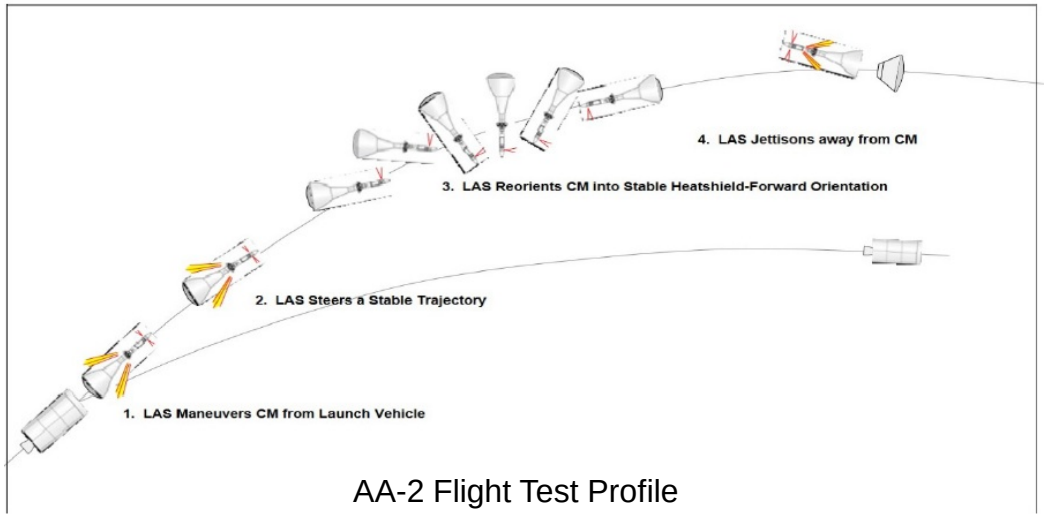
Extended wear clothing

Multi-Purpose Cargo Transfer Bag

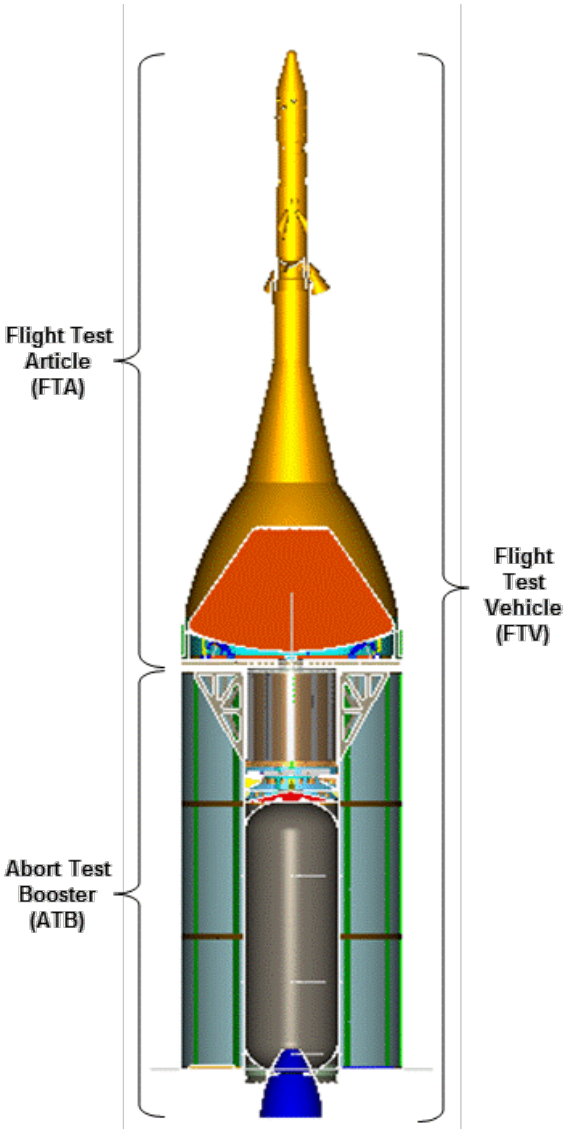
Astrobee free flyer

Ascent Abort 2 (AA-2) Flight Test

- A flight test of Orion's Launch Abort System under high dynamic pressure conditions is planned for December 2019.
- AES is providing workforce to integrate crew module with separation ring.
- In FY16, the project will complete a technical review and begin testing prototype avionics, power, and software in a FlatSat test bed.

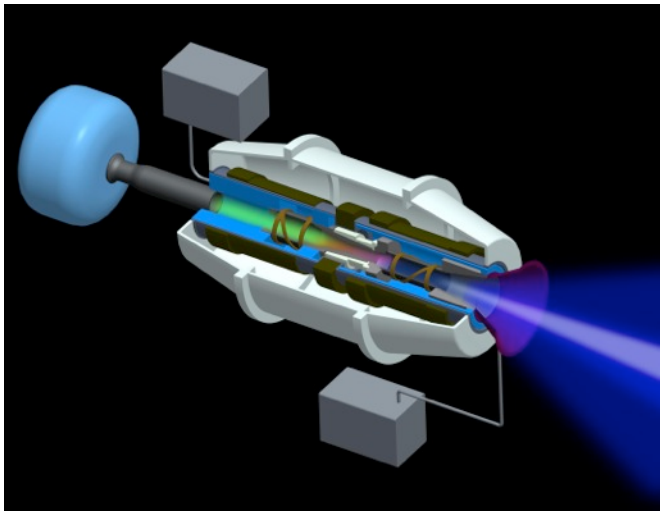


AA-2 Flight Test Profile

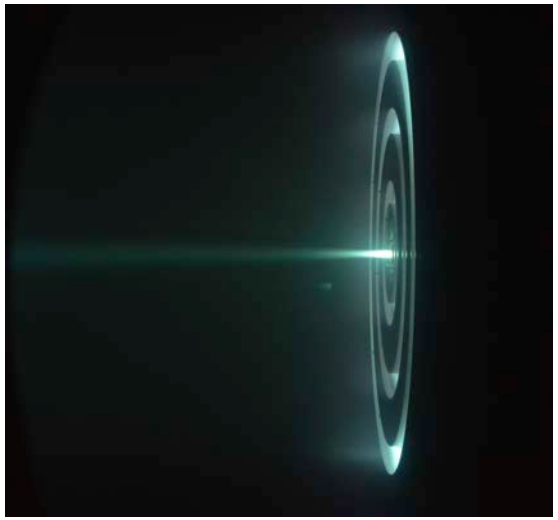


Advanced Propulsion

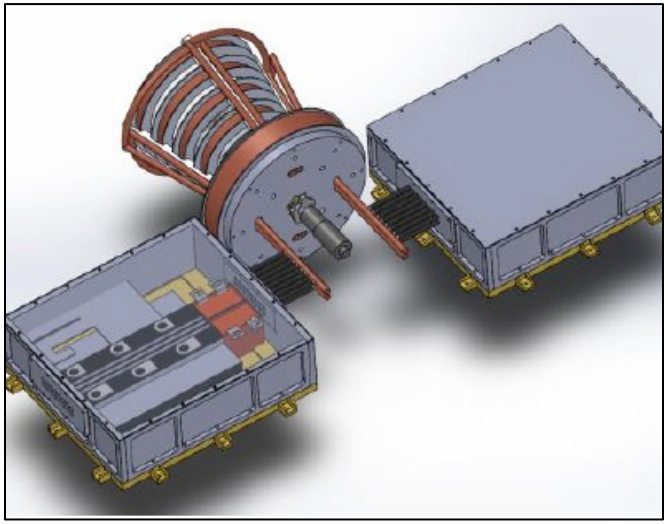
- NextSTEP partnerships to develop 100 kW electric thrusters and test them for 100 continuous hours.
- Maturing technology for next generation in-space propulsion systems following initial demonstration of 40 kW solar electric propulsion system for the Asteroid Redirect Mission.



Ad Astra Rocket Company: Thermal steady state testing of a VASIMR rocket core with scalability to human spaceflight



Aerojet Rocketdyne: Operational demonstration of a 100 kW electric propulsion system with nested Hall thruster

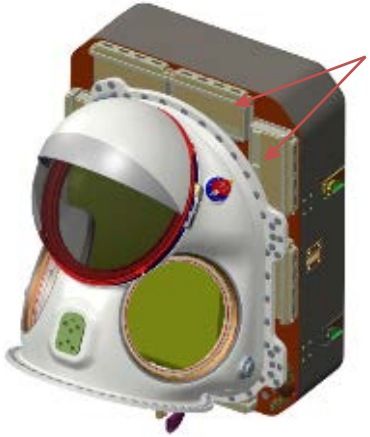


MSNW: Flexible high power electric propulsion for exploration class missions

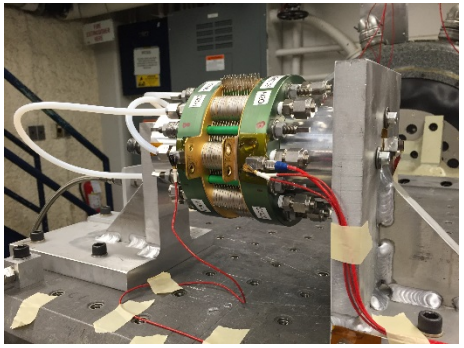
Modular Power Systems

- Developing a modular power interface standard and modular Power Distribution Units (PDU) for cislunar habitat.
- Developing advanced lithium-ion batteries for space suits to increase EVA duration.
- Qualifying non-flow through (NFT) fuel cells for SLS upper stage and developing regenerative fuel cells for surface systems.

Modular PDU chassis



Space suit battery packs



Vibration testing of NFT fuel cell

Ground & Mission Operations

Automated Propellant Loading:

- Automated cryogenic propellant handling and storage to reduce ground operations costs.
- Demonstrated automated liquefaction, transfer, and zero loss storage of LH2.

Autonomous Systems & Operations:

- Software tools to reduce crew's dependence on ground-based mission control.
- Demonstrated advanced caution and warning system on EFT-1.
- Demonstrated automated power up and configuration of EXPRESS rack on ISS.

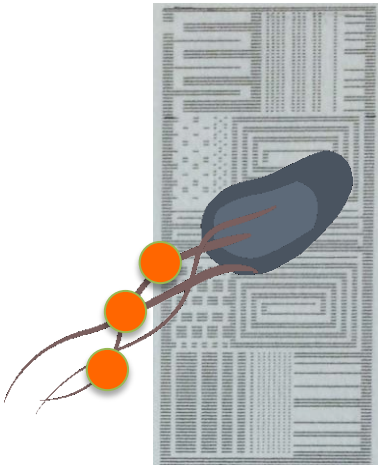
Avionics, Software, & Communications

- **Avionics & Software:** Developing common avionics components and architectures and Core Flight Software for exploration systems.
- **Disruption Tolerant Networking (DTN):** Infusion of store and forward communications protocols into NASA and international missions.
- **Ka-Band Objects Observation & Monitoring (KaBOOM):** Demonstrating antenna arrays with atmospheric disturbance compensation for future space communications and radar applications.

Quad-voting flight computers with Time Triggered Ethernet

KaBOOM array at KSC

In-Space Manufacturing & Synthetic Biology



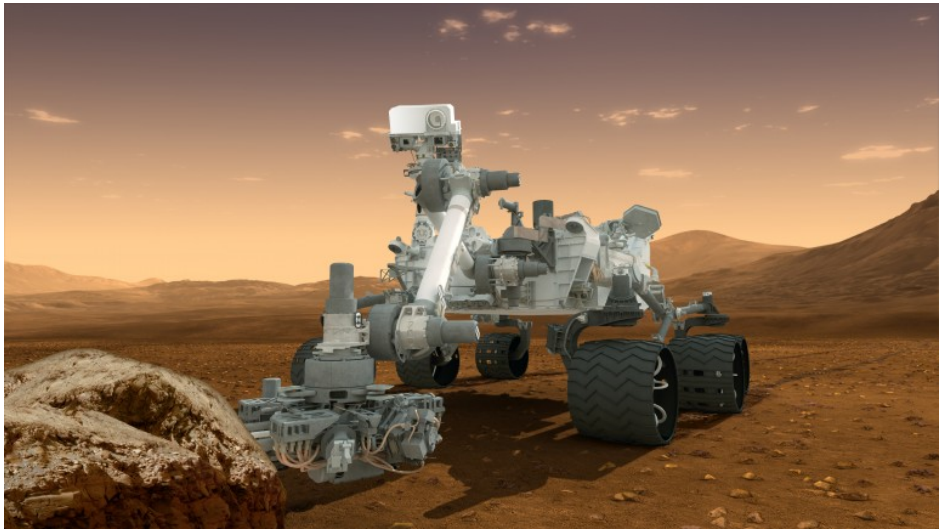
In-Space Manufacturing:

- Demonstrated first 3D printer on ISS to fabricate spare parts.
- Launching commercial Advanced Manufacturing Facility to ISS in 2016.
- Developing recycler to convert discarded plastic into feedstock for 3D printer.
- Partnership with DARPA to award contracts for External In-Space Manufacturing BAA.

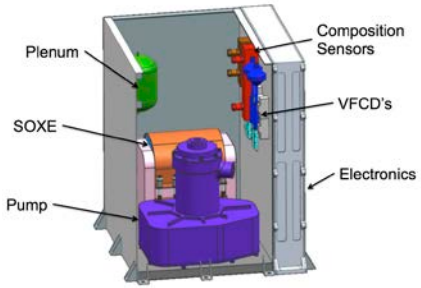
Synthetic Biology Applications:

- Genetically engineering microorganisms to produce bionutrients to supplement crew food supplies, and to produce feedstock molecules from carbon dioxide for in-space manufacturing.
- Pursuing public-private partnerships to infuse synthetic biology into related commercial applications and to promote sustainability.

Mars 2020 Payloads

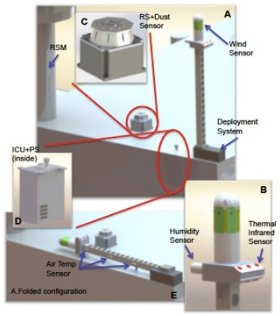


Mars 2020 payloads to demonstrate key technologies and address Strategic Knowledge Gaps for human missions are being jointly developed by AES and STMD.



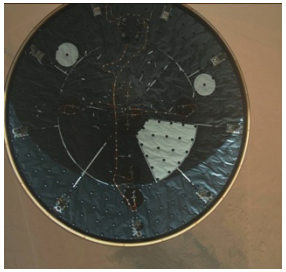
Mars Oxygen ISRU Experiment (MOXIE):

- Demonstrating production of oxygen from Mars atmosphere.
- Completed PDR in Jan. 2016.



Mars Environmental Dynamics Analyzer (MEDA):

- Surface weather station.
- Completed PDR in Nov. 2015.

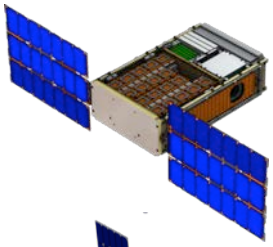


Mars Entry, Descent, & Landing Instrumentation (MEDLI-2):

- Temperature and pressure sensors on heat shield to validate aerothermal models.
- Completed SRR in Sep. 2015

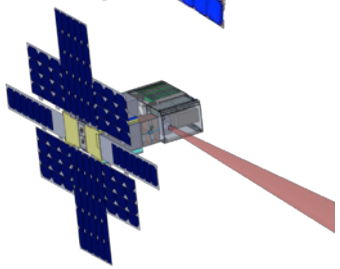
EM-1 Secondary Payloads

- **Biosentinel (ARC)**
  - Investigating the effects of deep space radiation on yeast DNA.
  - Testing microfluidics breadboard and conducting radiation testing on biosensor.



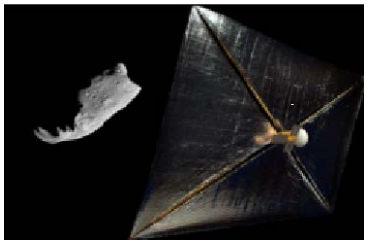
BioSentinel

- **Lunar Flashlight (JPL)**
  - Searching for volatiles in shadowed lunar craters..
  - Decided to replace solar sail with chemical propulsion system and use lasers to illuminate shadowed craters to maintain science objectives.
  - JPL providing IRIS radios for all EM-1 secondary payloads



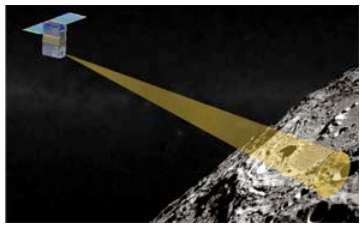
Lunar Flashlight

- **NEA Scout (MSFC)**
  - Flying by a near-Earth asteroid using a solar sail.
  - Completed structural and thermal tests of booms and deployment test of half-scale sail.



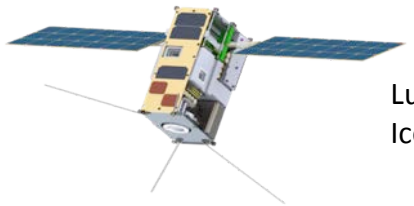
NEA Scout

- **SkyFire (Lockheed Martin)**
  - Flying by the Moon to test IR imager and then returning to GEO to demonstrate rendezvous and proximity operations.
  - Awarded NextSTEP contract



SkyFire

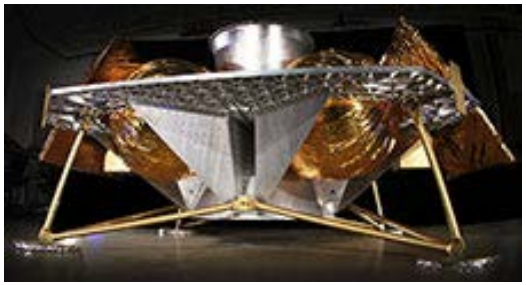
- **Lunar IceCube (Morehead State University)**
  - Prospecting for water ice using a compact IR spectrometer.
  - Awarded NextSTEP contract.
  - Upgrading 21-meter antenna at MSU to communicate with all EM-1 CubeSats.



Lunar IceCube

Lander Technology

Moon Express



Astrobotic Technologies

Masten Space Systems

Lunar CATALYST:

- Competitively selected partners awarded unfunded Space Act Agreements to stimulate commercial capabilities for lunar payload delivery.

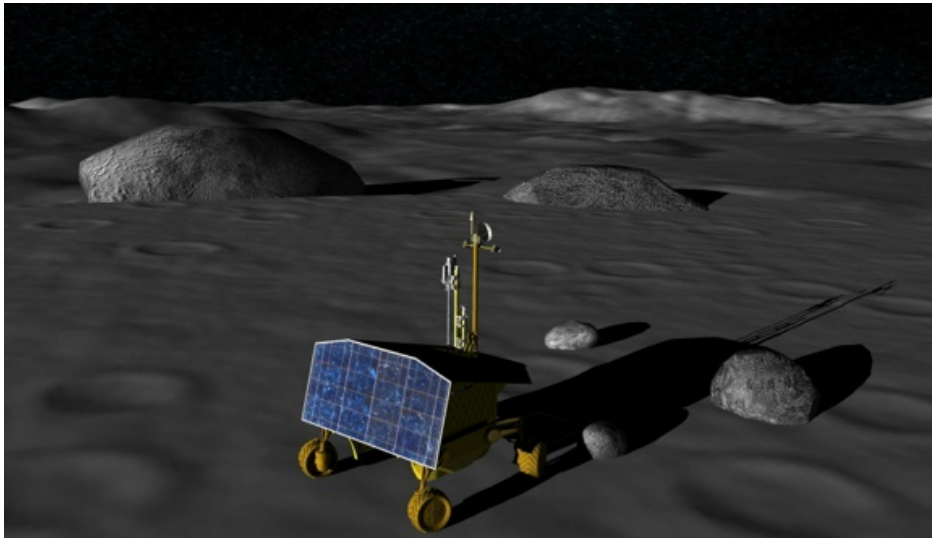
- NASA contributes technical expertise, test facilities, hardware and software.

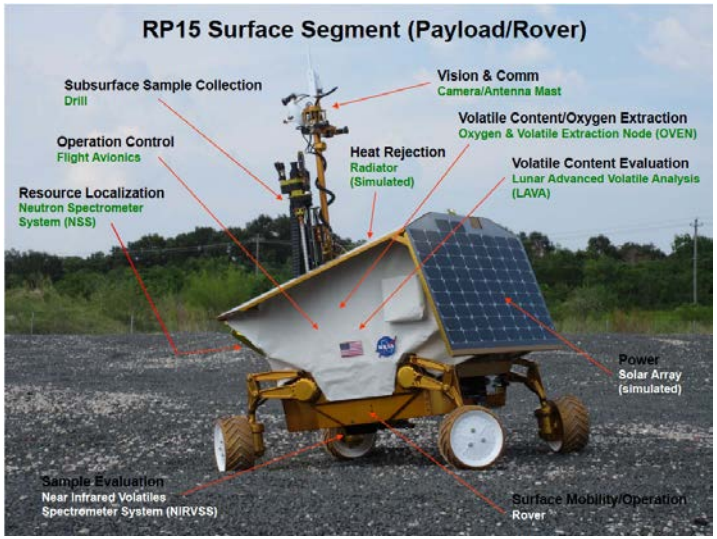
- FY16 activities:
  - PDR for Moon Express micro-lander
  - CDR for Astrobotic lander
  - Main engine hot fire test for Masten lander
  - Issue solicitation for lunar payload delivery services.

Autonomous Landing Technologies:

- Complete flight testing of Navigation Doppler Lidar and Lander Vision System on Flight Opportunities Program (Masten) lander.

Resource Prospector





- Resource Prospector is a robotic mission to the polar regions of the Moon to prospect for ice and demonstrate in-situ resource utilization. Targeting launch in 2021.
- Pursuing partnership with Taiwan for lander development. Lander concept study will be completed in July 2016.
- STMD is developing a prototype rover.
- Conducted integrated test of rover and prospecting payload in JSC rock yard.

Major FY16 Milestones

- ✓ **Jan 2016** **Mars 2020:** MOXIE Preliminary Design Review
- ✓ **Mar 2016** **Spacecraft Fire Safety:** Saffire-I flight experiment launch
- **Apr 2016** **BEAM:** Launch to ISS
- **Apr 2016** **EM-1 Secondary Payloads:** Complete BioSentinel Critical Design Review
- **May 2016** **Ascent Abort-2:** System Requirements Review
- **Jun 2016** **Spacecraft Fire Safety:** Saffire-II flight experiment launch
- **Jun 2016** **Lunar CATALYST**: Critical Design Review for Astrobotic lander
- **July 2016** **Resource Prospector:** Complete lunar lander study with Taiwan
- **Aug 2016** **NextSTEP**: Complete subsystems for VASIMR test article
- **Aug 2016** **EM-1 Secondary Payloads**: Complete NEA Scout & Lunar Flashlight design reviews
- **Aug 2016** **NextSTEP:** Award Phase 2 contracts for cis-lunar habitat development.
- **Sep 2016** **Mars 2020:** MOXIE Critical Design Review**.**

FY17 Plans

- **Continue development of prototype cislunar habitats in Phase 2 of NextSTEP partnerships.**

- **In-Situ Resource Utilization Technology**
  - Begin development of technologies to extract water and other volatiles from regolith (Moon, asteroids, Mars), and to scale-up production of oxygen and methane from the Mars atmosphere.
  - Approach includes BAA for external partnerships to develop components and subsystems, and in-house effort to integrate and test systems.

HEOMD/STMD Engagement on Technology Needs

- **Evolvable Mars Campaign (EMC) has a strategic set of needs for enabling long-range capabilities; Orion and SLS needs are primarily near-term and mission focused.**
- **Crosscutting needs identified by HEOMD:**
  - Radiation monitoring & protection (ISS, Orion, HRP, EMC)
  - EVA suit & PLSS (Orion, ISS, ARM, EMC)
  - Environmental monitoring (Orion, ISS, EMC)
  - Spacecraft fire safety (Orion, ISS, EMC)
  - Exercise equipment (Orion, HRP, EMC)
  - Advanced solar arrays (ARM, ISS, EMC)
  - Automated rendezvous & docking (Orion, ARM, EMC)
- **Areas with greatest number of gaps:**
  - Human Health, Life Support, & Habitation Systems (Orion, HRP)
  - Communications & Navigation (SCAN)
- **Categories of collaboration:**
  - **Deliveries:** STMD matures technology and delivers to AES for system-level evaluation (e.g advanced space suit components.)
  - **Partnerships:** STMD and HEOMD/AES co-fund the development of technologies that are of mutual interest (e.g. Mars 2020 payloads.)
  - **Coordination:** STMD and HEOMD/AES define specific divisions of responsibility within a technical discipline (e.g. synthetic biology, advanced manufacturing, etc.)

Summary

- AES launched the first Saffire fire safety flight experiment on March 22, and the Bigelow Expandable Activity Module will launch in April.
- AES is using the NextSTEP public-private partnerships to develop a prototype cis-lunar habitat and habitation systems by 2018.
- AES is developing 10 ISS flight experiments to demonstrate life support and environmental monitoring systems for a cis-lunar habitat.
- AES is developing five CubeSats for launch on EM-1 to address Strategic Knowledge Gaps.
- AES is partnering with STMD and SMD to develop three payloads for the Mars 2020 mission that will demonstrate enabling technologies and gain knowledge for human exploration.