National Aeronautics and Space Administration

ADVANCED EXPLORATION SYSTEMS

NASA Advisory Council
Technology, Innovation, and Engineering Committee

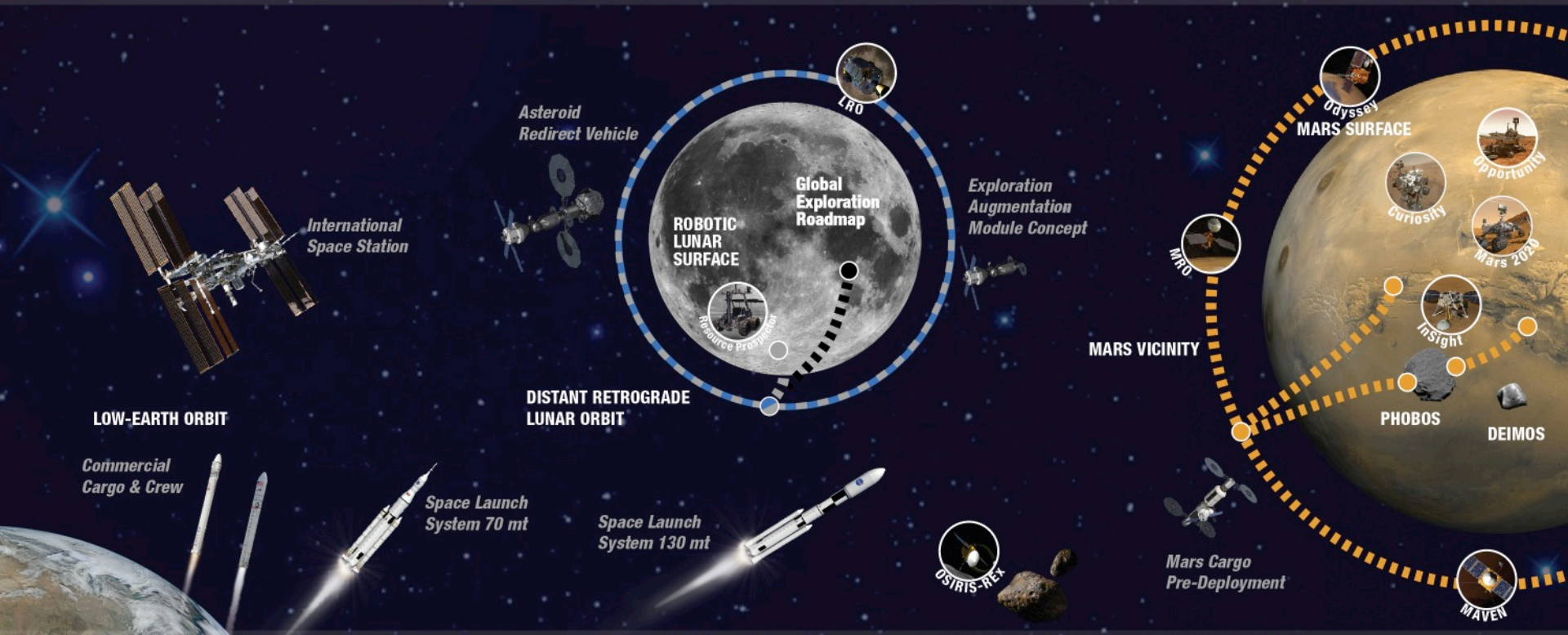
December 4, 2014

Dr. Chris Moore

EVOLVABLE MARS CAMPAIGN

A Pioneering Approach to Exploration

EARTH RELIANT | PROVING GROUND | EARTH INDEPENDENT



THE TRADE SPACE

Across the Board | Solar Electric Propulsion • In-Situ Resource Utilization (ISRU) • Robotic Precursors • Human/Robotic Interactions • Partnership Coordination • Exploration and Science Activities

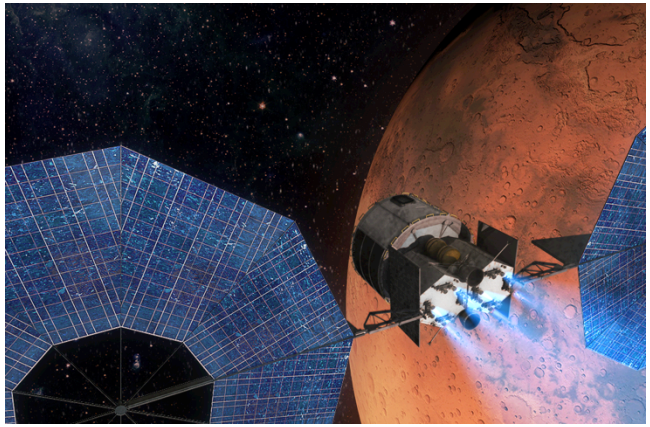
Cis-lunar Trades

- Deep-space testing and autonomous operations
- Extensibility to Mars
- Mars system staging/refurbishment point and trajectory analyses

Mars Vicinity Trades

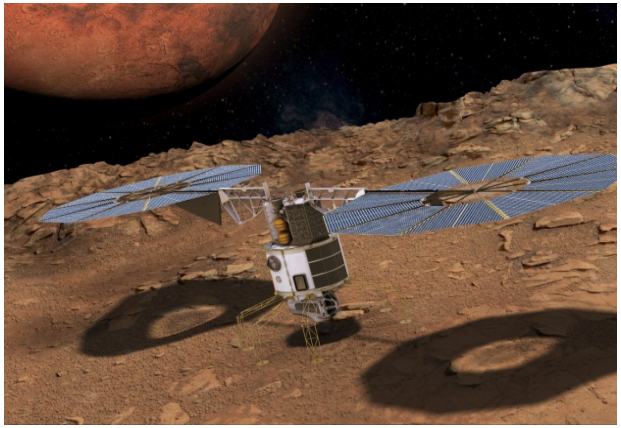
- Split versus monolithic habitat
- Cargo pre-deployment
- Mars Phobos/Deimos activities
- Entry descent and landing concepts
- Transportation technologies/trajectory analyses

Mars Vicinity Options Provide the "Pull"



Mars Orbit

- Opportunities for integrated human-robotic missions:
  - Real time tele-operation on Martian surface
  - Mars sample return
  - Other science objectives
  - Technology demonstrations
- Demonstrate sustainable human exploration split-mission Mars concept
- Validate transportation and long-duration human systems
- Validate human stay capability in zero/micro-g

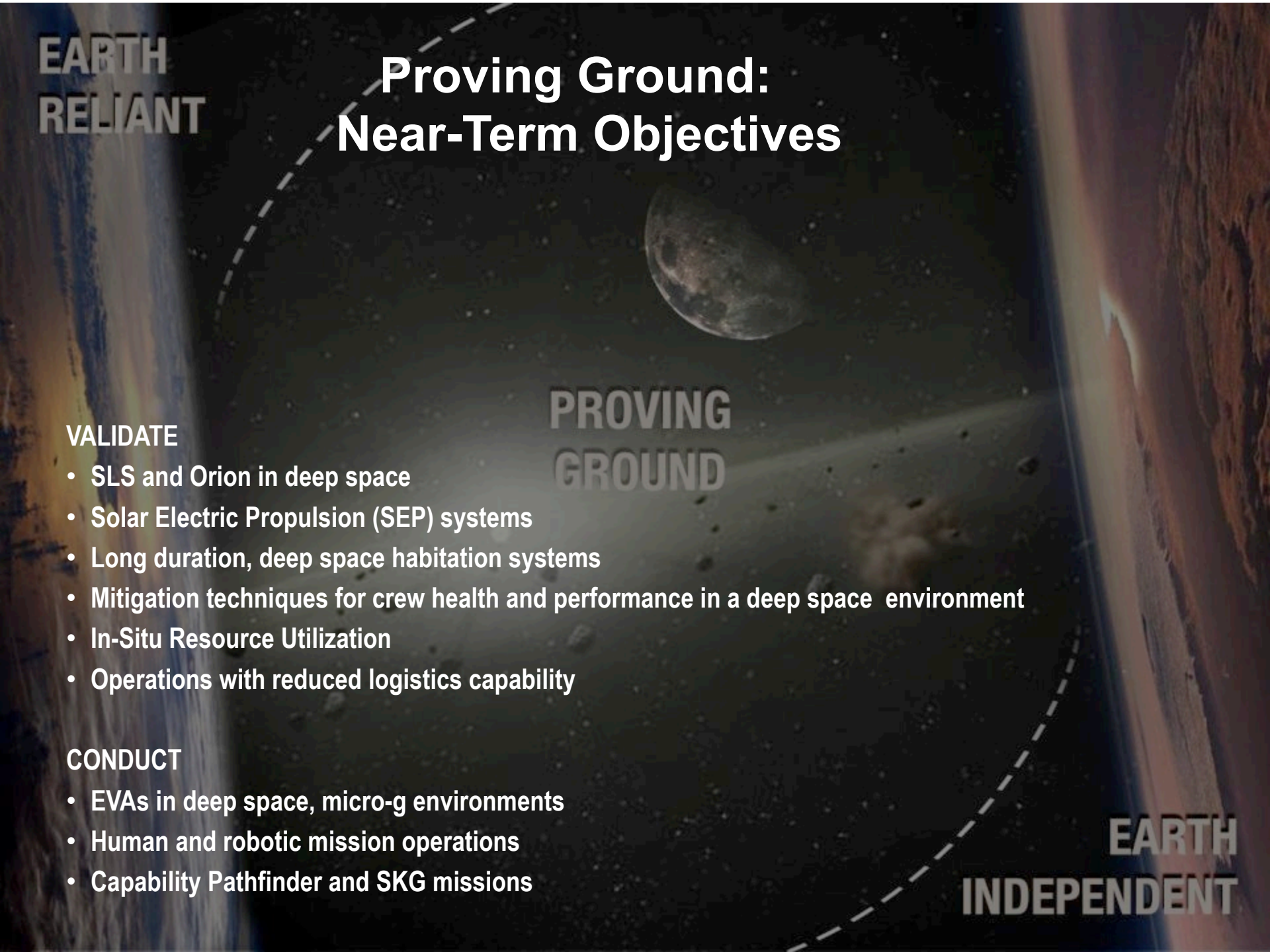


Mars Moons

- Opportunities for integrated human-robotic missions:
  - Real time tele-operation on Martian surface
  - Mars & moons sample return
  - Other science objectives
  - Technology demonstrations
- Demonstrate sustainable human exploration split-mission Mars concept
- Moons provides additional radiation protection
- In-situ resource utilization
- Validate human stay capability in low-g environment

Mars Surface

- Opportunities for integrated human-robotic missions:
  - Search for signs of life
  - Comparative planetology
  - Understanding Mars climate changes
  - Geology/geophysics
- Planet provides radiation protection
- Entry, descent, landing
- EVA surface suits
- In-situ resource utilization
- Validate human stay capability in partial-g



Proving Ground: Near-Term Objectives

VALIDATE

- SLS and Orion in deep space
- Solar Electric Propulsion (SEP) systems
- Long duration, deep space habitation systems
- Mitigation techniques for crew health and performance in a deep space environment
- In-Situ Resource Utilization
- Operations with reduced logistics capability

CONDUCT

- EVAs in deep space, micro-g environments
- Human and robotic mission operations
- Capability Pathfinder and SKG missions

ADVANCED EXPLORATION SYSTEMS

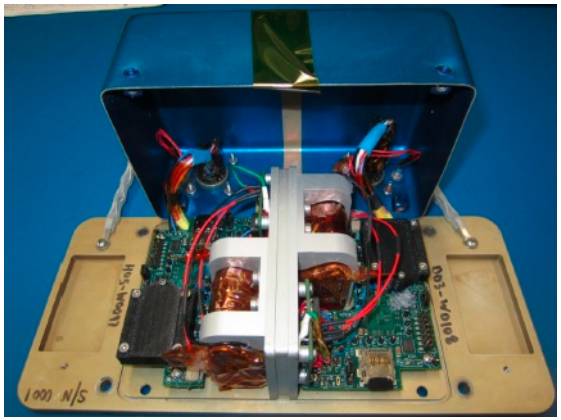
Rapid development and testing of prototype systems and validation of operational concepts to reduce risk and cost of future exploration missions:

- **Crew Mobility Systems**
  - Systems to enable the crew to conduct "hands-on" surface exploration and in-space operations, including crew excursion vehicles, advanced space suits, and crew egress
- **Deep Space Habitation Systems**
  - Systems to enable the crew to live and work safely in deep space, including deep space habitats, reliable life support, radiation protection, and fire safety
- **Vehicle Systems**
  - Systems for in-space propulsion stages and small robotic landers, including nuclear propulsion, modular power systems, lander technology test beds, and autonomous precision landing
- **Operations**
  - Systems to enable more efficient mission and ground operations, including integrated testing, autonomous mission ops, integrated ground ops, and logistics reduction
- **Robotic Precursor Activities**
  - 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

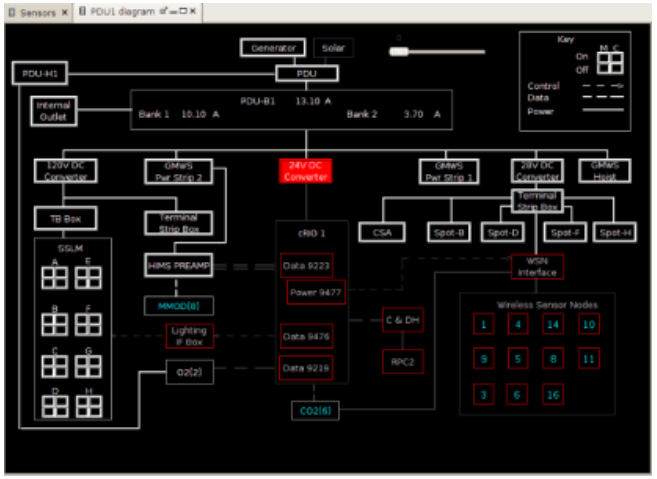
Summary for FY15

- AES has established 77 milestones for FY15
- Over 60% include flight demonstration elements
- Goal to achieve at least 80%
- AES includes 580 civil servants in FY15

EFT-1 FLIGHT EXPERIMENTS



Radiation Environment Monitors will measure radiation inside Orion when it passes through Van Allen belts.

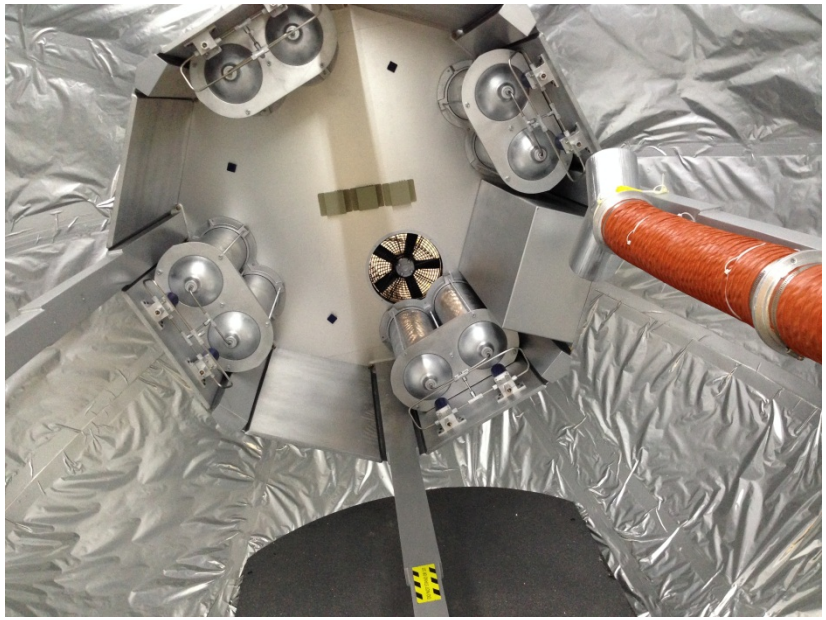


Advanced Caution & Warning System will operate in shadow mode during flight to detect faults in Orion power system.

BIGELOW EXPANDABLE ACTIVITY MODULE (BEAM)

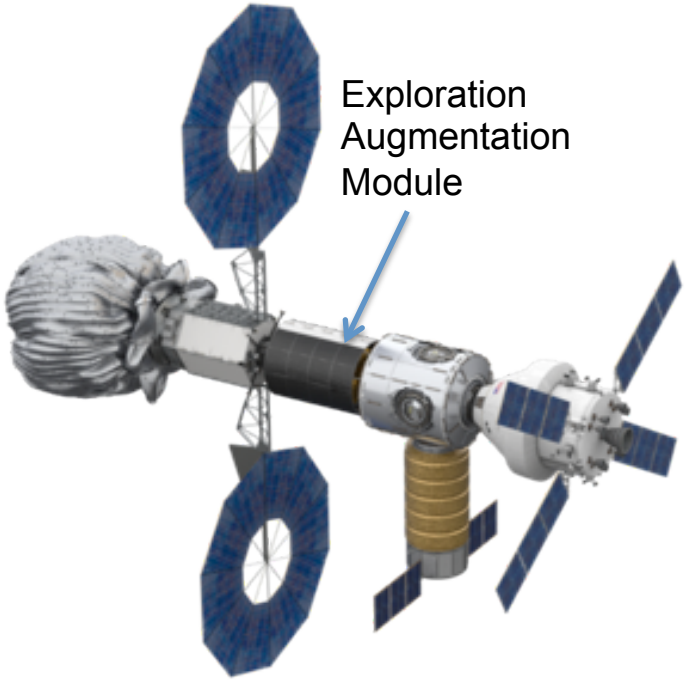
- A mockup of the Bigelow Expandable Activity Module (BEAM) was delivered to JSC for integrated sensor testing and crew training.
- Completed critical design reviews on the primary integrated structure and flight support equipment.
- Completed all structural tests including pressurization, rapid depressurization, random vibration, and modal survey.
- Passive Common Berthing Mechanism will be integrated with BEAM in December.
- Project is on schedule to launch BEAM in September 2015 on SpaceX-8 mission.

BEAM mockup exterior

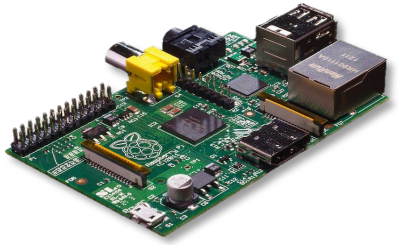


BEAM mockup interior

EXPLORATION AUGMENTATION MODULE



- An Exploration Augmentation Module (EAM) in cis-lunar space could provide extra logistics to extend Orion's mission to 30-60 days.
- The EAM could be used to test deep space habitation technologies for a Mars transport habitat.
- AES is integrating avionics & software, modular power systems, and life support systems into EAM test bed.
- NextSTEP BAA is soliciting proposals for commercial partnerships to develop EAM concepts.



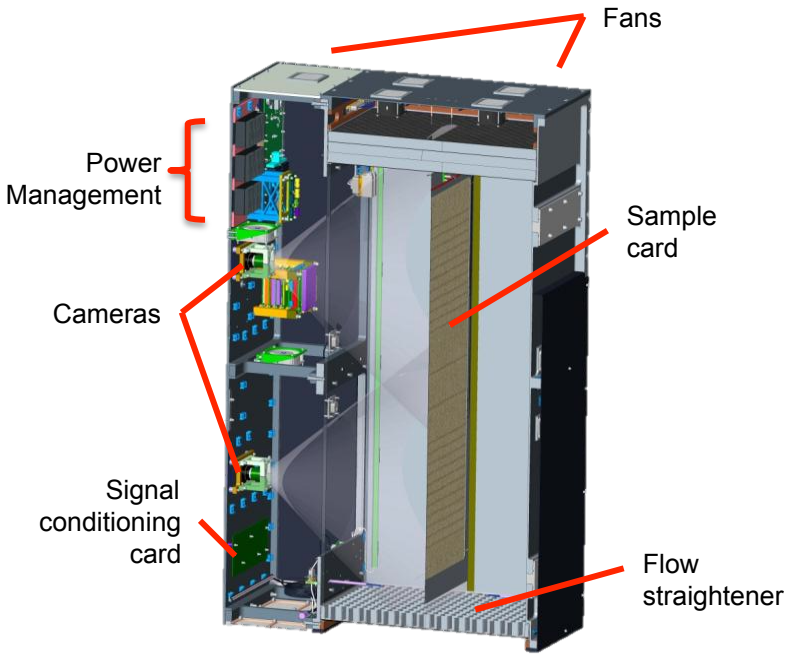
Avionics & Software

Modular Power Systems

ECLSS

SPACECRAFT FIRE SAFETY

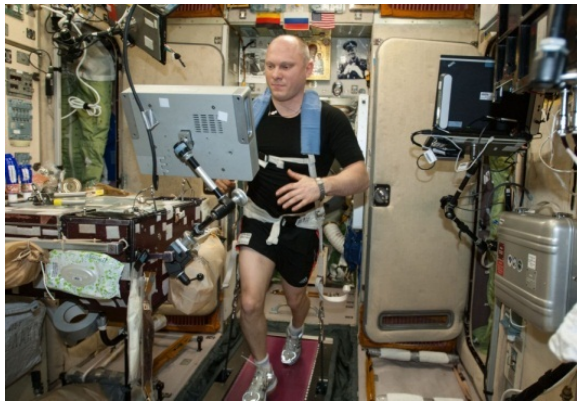
- Series of three flight experiments on Cygnus to investigate how large-scale fires propagate in microgravity.
- Completed assembly and environmental tests of Saffire flight unit #1.
- Interface test with Cygnus planned for March 2015. Launch date uncertain due to Antares failure.



Saffire Fire Safety Experiment

LOGISTICS REDUCTION

- ISS crew demonstrated extended wear clothing to reduce the mass of laundry on long missions.
- Developing Universal Waste Management System (toilet) with reduced volume and complexity for Orion and EAM.
- Developing Heat Melt Compactor to reduce the volume of trash on ISS.
- Developing RFID readers to track inventory and to locate missing items quickly.



Extended wear clothing

Heat Melt Compactor

IN-SPACE MANUFACTURING

- 3D Printer launched to ISS on SpaceX-4 mission. The printer was installed in the Microgravity Science Glovebox, and the first part was successfully printed on November 24.

- In-space manufacturing capabilities will reduce logistics for deep space missions by enabling production of tools and spare parts on demand.

- Announced a “Future Engineers” challenge conducted under a partnership with ASME in which students will design parts for 3D printing on ISS.

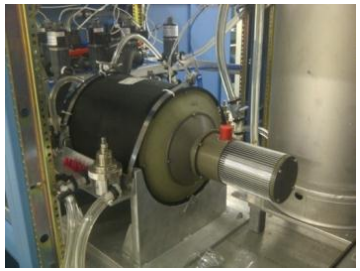
3D Printer in Microgravity Science Glovebox

First part printed on ISS

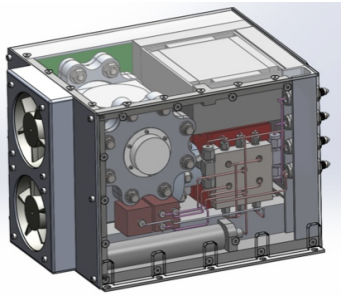
LIFE SUPPORT

Air Revitalization: Developing improved CO_2 sorbents and high-pressure oxygen generation system.

Water Recovery: Developing cascade distillation system and non-toxic urine pretreatments to recycle wastewater.



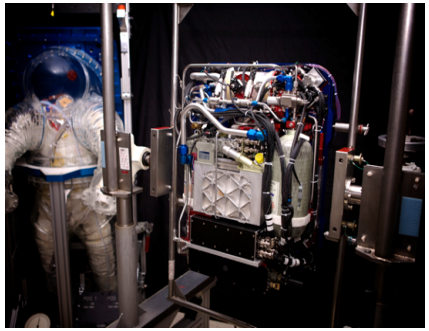
Environmental Monitoring: Developing Micro Total Atmospheric Monitor to identify hazardous contaminants.



Integrated systems testing and flight demonstrations of ISS-derived life support components to improve reliability and performance.

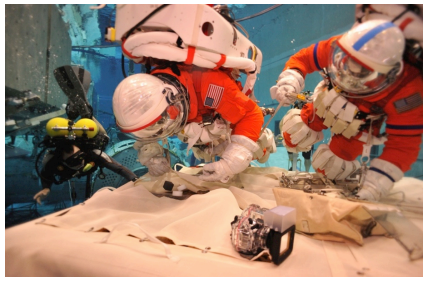
ADVANCED EVA

Development and testing of next generation space suits and portable life support systems



Portable Life Support System 2.0:

- First new space suit system developed since 1981.
- Incorporates new technology components for CO_2 removal, pressure regulation, thermal control, and energy storage.
- Completed human-in-the-loop testing with pressurized suit.



Modified Advanced Crew Escape Suit (MACES):

- Developing short duration space suit for Asteroid Redirect Mission.
- Validated operational concepts for asteroid EVA in Neutral Buoyancy Lab tests.

Z-3 Suit:

- Working towards demonstration of advanced exploration space suit on ISS in 2021.

GROUND & MISSION OPERATIONS

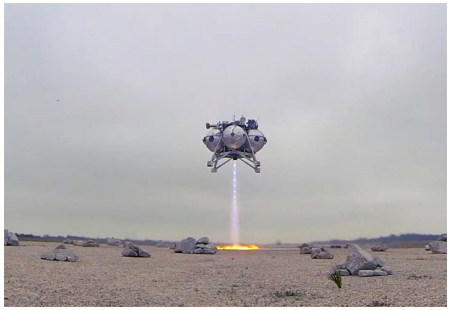
Automated Propellant Loading:

- Automated cryogenic propellant handling and storage to reduce ground operations costs.
- Demonstrated automated loading of 2000 gallon LOX tank.
- Plan to demonstrate liquefaction, zero loss storage, and densification of LH2 in FY15.

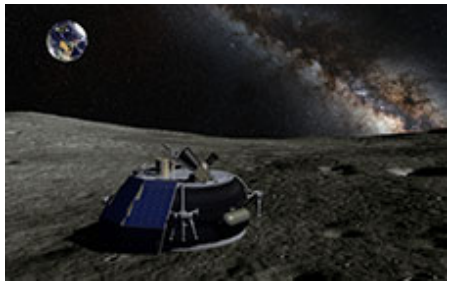
Autonomous Systems & Operations:

- Software tools to reduce crew's dependence on ground-based mission control.
- Demonstrated status monitoring of Total Organic Carbon Analyzer and ISS laptop computers.
- Demonstrated automated power up and configuration of EXPRESS rack on ISS.

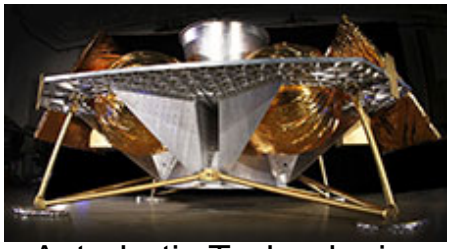
LANDER TECHNOLOGY



Morpheus/ALHAT



Moon Express



Astrobotic Technologies

Masten Space Systems

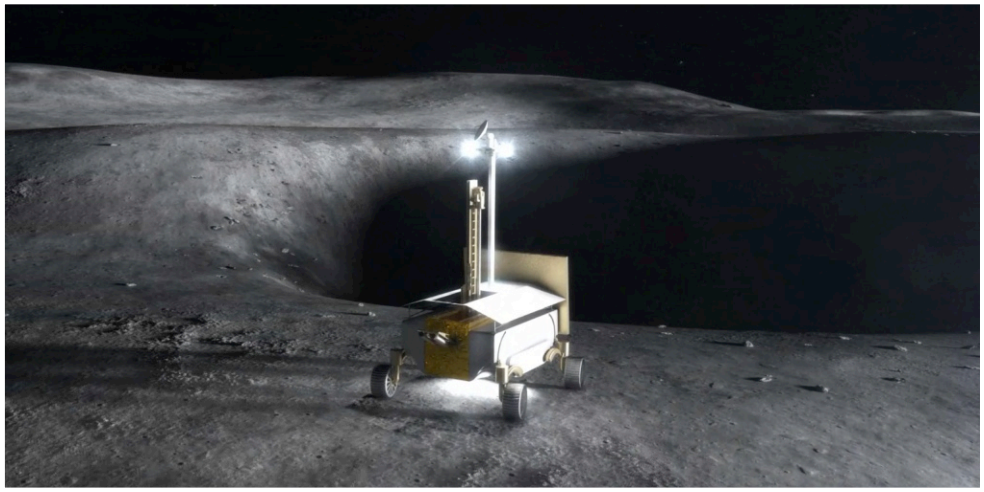
Morpheus/ALHAT:

- Completed two closed-loop flight tests of autonomous landing and hazard avoidance (ALHAT) system on Morpheus lander at KSC.
- Two more flight tests are planned in December to resolve issues with laser Doppler velocimeter.

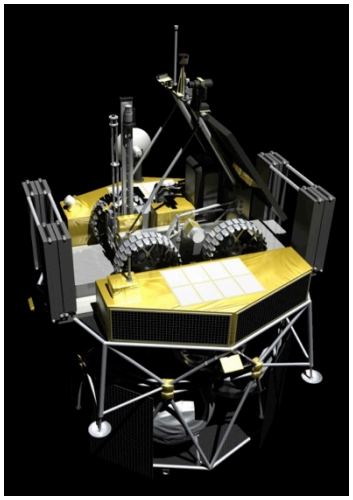
Lunar CATALYST:

- 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.
- Major FY15 objectives:
  - Moon Express: tether test of lander.
  - Astrobotic Technologies: end-to-end mission simulation.
  - Masten Space Systems: propulsion system PDR.

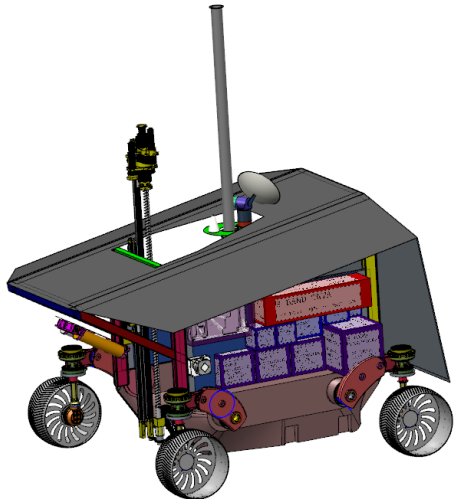
RESOURCE PROSPECTOR (RP)



- Resource Prospector is a robotic mission to the polar regions of the Moon to prospect for ice and demonstrate in-situ resource utilization.
- Pursuing partnership with JAXA. Targeting launch in 2020.
- STMD is developing a prototype rover.
- Integrated test of rover and prospecting payload is planned in FY15.



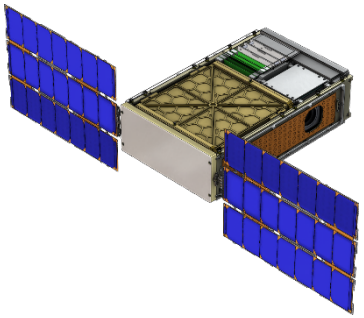
JAXA lander concept



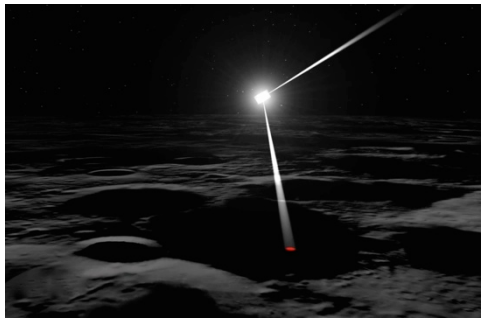
NASA rover concept

EM-1 SECONDARY PAYLOADS

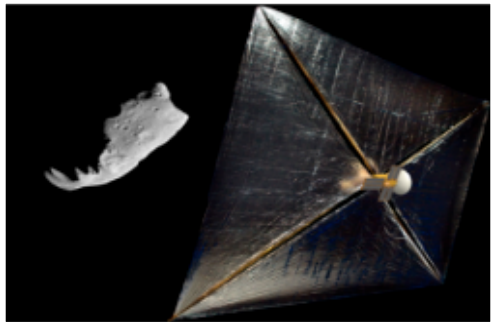
- SLS is capable of launching 11 6U-CubeSats.
- AES is developing 3 EM-1 secondary payloads to address key Strategic Knowledge Gaps.
- Additional EM-1 secondary payloads are being solicited via the NextSTEP BAA.



BioSentinel: Investigating effects of deep space radiation on yeast DNA.

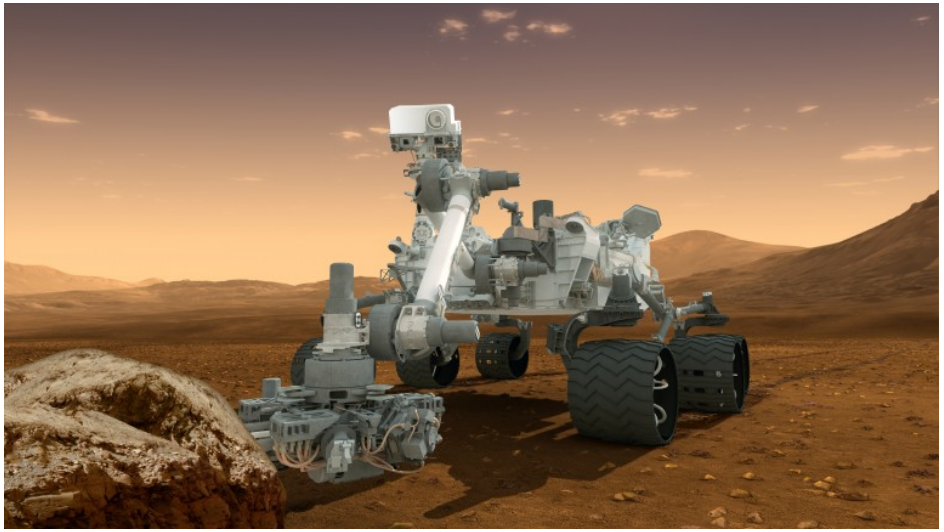


Lunar Flashlight: Searching for volatiles in shadowed lunar craters.

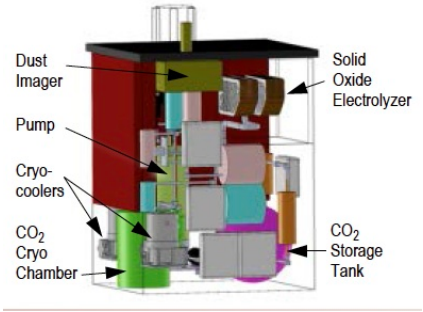


NEA Scout: Fly by of near-Earth asteroid.

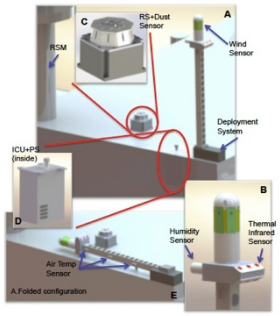
MARS 2020 PAYLOADS



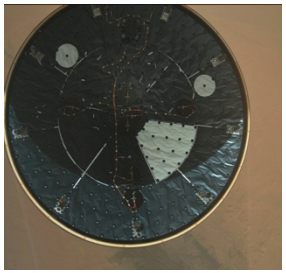
Mars 2020 payloads to demonstrate key technologies and address Strategic Knowledge Gaps for human missions are being jointly developed by AES and STMD.



Mars Oxygen ISRU Experiment (MOXIE): Demonstrating production of oxygen from Mars atmosphere.

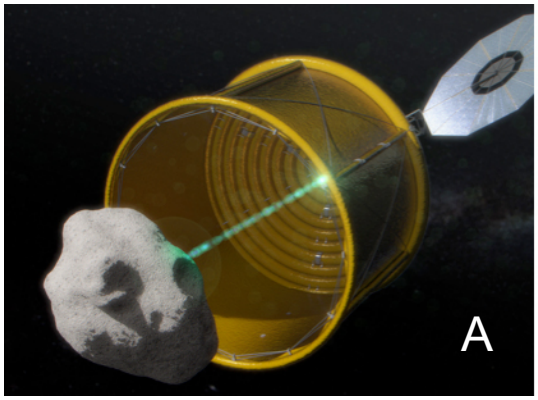


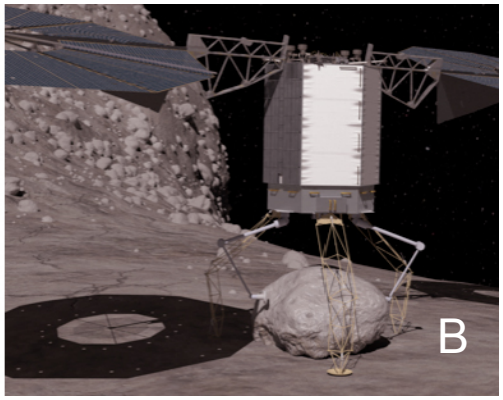
Mars Environmental Dynamics Analyzer (MEDA): Surface weather station.



Mars Entry, Descent, & Landing Instrumentation (MEDLI-2): Temperature and pressure sensors on heat shield to validate aerothermal models.

ASTEROID CAPTURE SYSTEMS



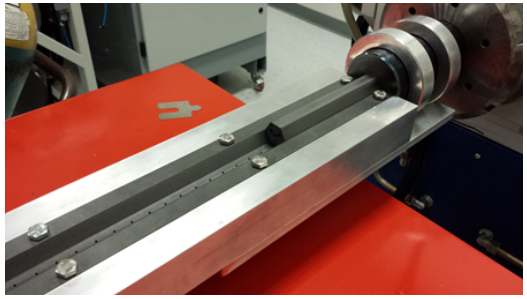


- AES is developing asteroid capture systems for the Asteroid Redirect Mission.
- Awarded four BAA contracts for industry-led studies of capture system concepts:
  - Airborne Systems (Option A)
  - Jacobs (Option A)
  - Space Systems Loral (Option B)
  - Altius Space Machines (Option B)
- Mission options down select decision in mid-December.

1/5-scale proof-of-concept inflatable asteroid capture system (JPL)

ADVANCED IN-SPACE PROPULSION

- Fabricating and testing of reactor fuel elements for nuclear thermal propulsion in partnership with DOE.
- Independent Review Panel will make fuel element down selection recommendation in Feb. 2015.
- Next phase is assessment of affordable ground test approaches of nuclear rocket engines.
- Goal is flight demonstration of small (7,500 lb thrust) nuclear rocket engine.
- NextSTEP BAA is soliciting commercial partnerships for development and ground testing of high-power electric propulsion systems (> 100 kW).



Graphite Composite Fuel Element (DOE)

Cermet Fuel Element (NASA)

Nuclear Thermal Rocket Element Environmental Simulator (NTREES)

FY15 AES PROJECTS

- Autonomous Systems & Operations
- Exploration Augmentation Module
- Advanced Space Suit
- Life Support
- Logistics Reduction
- In-Space Manufacturing
- Resource Prospector
- Lander Technology
- Radiation Sensors
- Spacecraft Fire Safety
- Avionics & Software
- Nuclear Thermal Propulsion
- Modular Power Systems
- SSERVI
- BEAM
- BioSentinel
- Lunar Flashlight
- NEA Scout
- Mars 2020 ISRU Demo (MOXIE)
- Mars 2020 Weather Station (MEDA)
- MEDLI-2
- Fiber Optic Sensors
- Composite Upper Stage
- Synthetic Biology Applications
- Automated Propellant Loading
- Ka-Band Objects Observation & Monitoring
- Disruption Tolerant Networking

MAJOR FY15 MILESTONES

Nov 2014 **In-Space Manufacturing:** Demonstrate 3D Printer on ISS.

Nov 2014 **Advanced Space Suit:** Complete human-in-the-loop testing.

Dec 2014 **Radiation Sensors**: Launch radiation environment monitor on EFT-1.

Dec 2014 **Autonomous Sys. & Ops**: Demonstrate Advanced Caution and Warning System on EFT-1.

Jan 2015 **Lander Technology:** Initiate collaborative activities with commercial partners.

Mar 2015 **BEAM:** Deliver flight hardware to KSC.

Apr 2015 **Exploration Augmentation Module:** Select public-private partnerships via BAA.

Apr 2015 **Nuclear Propulsion:** Complete testing of reactor fuel elements.

Jul 2015 **EM-1 Secondary Payloads:** Complete solar sail engineering development unit.

Aug 2015 **Resource Prospector**: Complete integrated systems test and mission simulation.

Aug 2015 **MOXIE:** Complete Instrument Preliminary Design Review.

Sep 2015 **Spacecraft Fire Safety:** Integrate Saffire flight unit #1 with Cygnus vehicle.

AES VISION FOR 2020

- Exploration Augmentation Module to extend Orion capabilities in cis-lunar space and to test deep space habitation and life support capabilities for Mars missions.

- Demonstration of advanced space suit on ISS for asteroid and Mars exploration.

- Strategic Knowledge Gap Robotic Precursor Missions, including the Resource Prospector to search for lunar ice, Mars 2020 in-situ oxygen production demonstration, follow-on EM-2 secondary payloads, and formulation of a Phobos precursor mission.

- Evolvable Mars Campaign precursor missions to test and emplace key systems on Mars such as EDL system for heavy payloads, in-situ propellant production plant, and surface power system aligned with SMD needs like Mars sample return.

- Development and testing of advanced in-space propulsion systems, including high-power electric propulsion for the efficient transport of cargo, and nuclear thermal propulsion to reduce the trip time for crewed missions.

SUMMARY

- **AES is developing the critical capabilities needed for human exploration of Mars:**
  - Advanced In-Space Propulsion
  - Deep Space Habitation
  - Life Support
  - EVA
  - In-Situ Resource Utilization
  - Autonomous Mission Operations

- **AES is pursuing flight demonstrations on ISS and in the proving ground of cis-lunar space.**

- **AES works closely with STMD to infuse new technologies.**