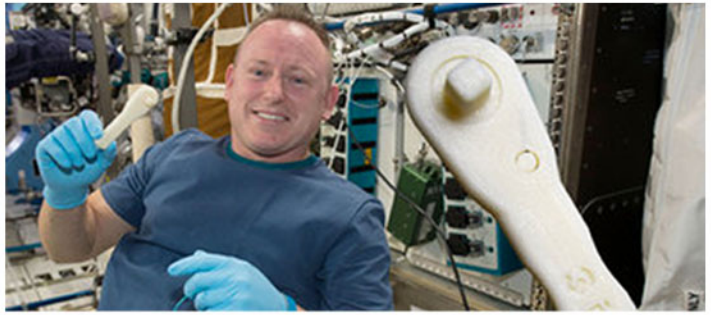
National Aeronautics and Space Administration




ADVANCED EXPLORATION SYSTEMS

HEO NAC Subcommittee
November 30, 2017

Jason Crusan, Director, Advanced Exploration Systems Division

Advanced Exploration Systems

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

- **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, and modular power systems.
- **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, CubeSats launched on EM-1, technology demonstrations on Mars 2020 mission, and instrument development.
- **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. Engage students and the public using crowd-sourced challenges and other open innovation activities.

EXPANDING HUMAN PRESENCE IN PARTNERSHIP

CREATING ECONOMIC OPPORTUNITIES, ADVANCING TECHNOLOGIES, AND ENABLING DISCOVERY

Now

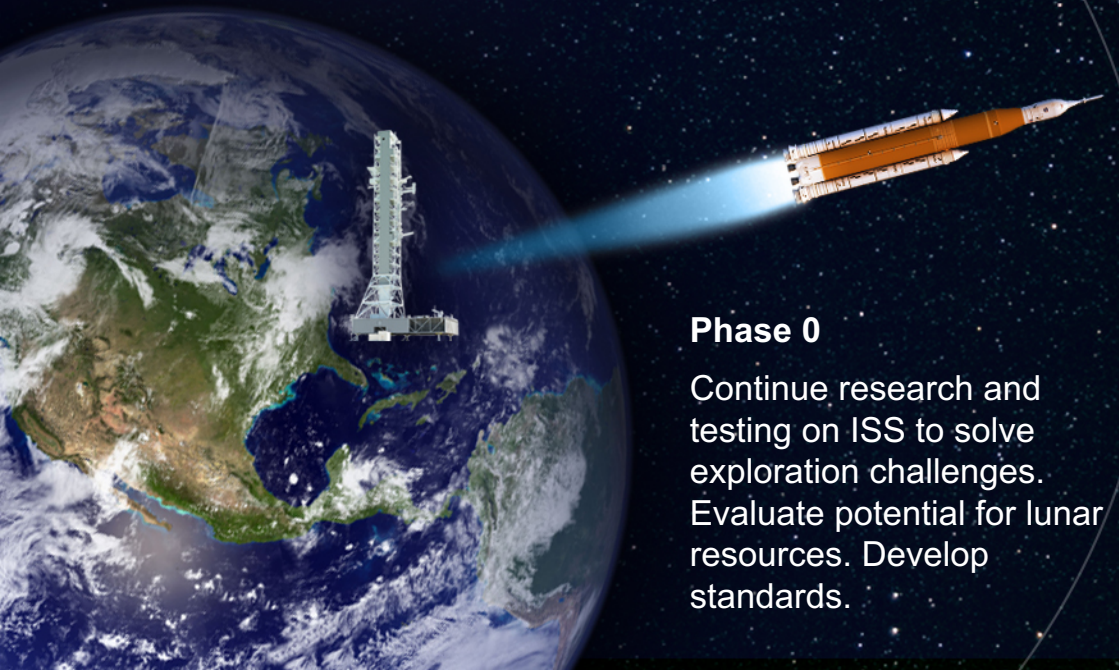
Using the International Space Station

2020s

Operating in the Lunar Vicinity (proving ground)

After 2030

Leaving the Earth-Moon System and Reaching Mars Orbit



Phase 0

Continue research and testing on ISS to solve exploration challenges. Evaluate potential for lunar resources. Develop standards.

Phase 1

Begin missions in cislunar space. Initiate next key deep space capability.

Phase 2

Complete next deep space capability and checkout.

Human Exploration Technology-Enabled Capabilities Timeline

PHASE 0 Exploration Systems Testing on ISS

- Life Support (recycle 90% air; 98% water)
- Human Health and Performance (1,100 day missions)

PHASE 2 Leaving the Earth-Moon System

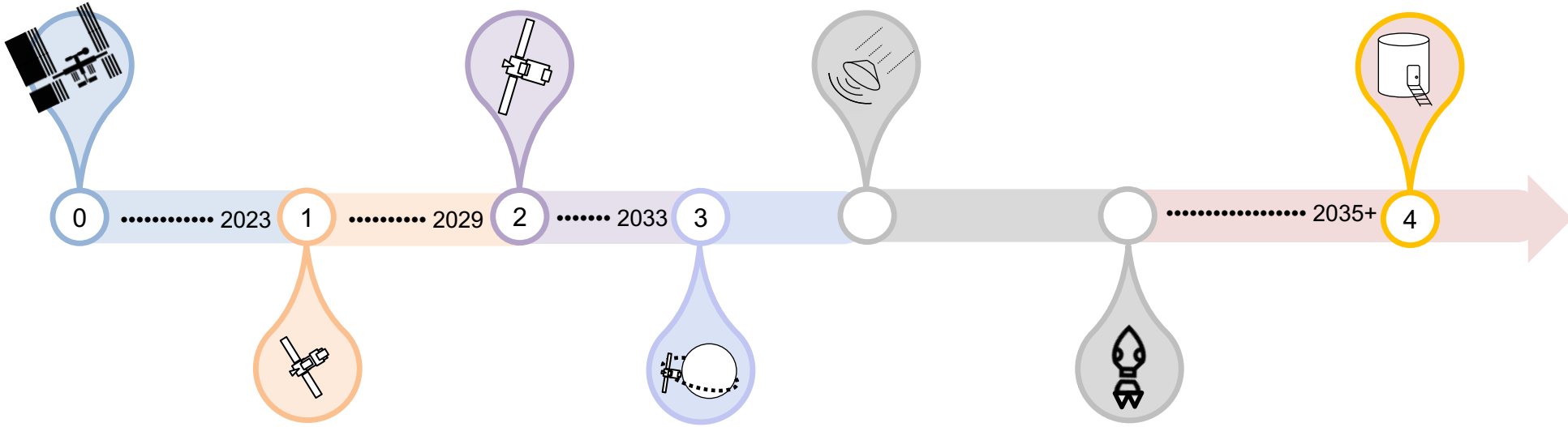
- Chemical propulsion
- Solar electric prop. (300 kW)
- Hybrid SEP/Chem Prop.

Mars EDL

- TPS (11 km/s)
- Supersonic Retro-Propulsion
- HIAD (Land 25 mT payloads)
- Auto Precision Landing (10 m)

PHASE 4 Human Mars Surface Capability

- Surface Habitat (500 days)
- Surface Power Sys (40 kW)
- EVA / Crew Mobility Sys (100 km)
- Planetary Protection



PHASE 1 Operating in the Lunar Vicinity

- Deep Space Habitat
- Radiation Protection
- Logistics Reduction
- Autonomous Operations
- SKG Lunar Resource Knowledge

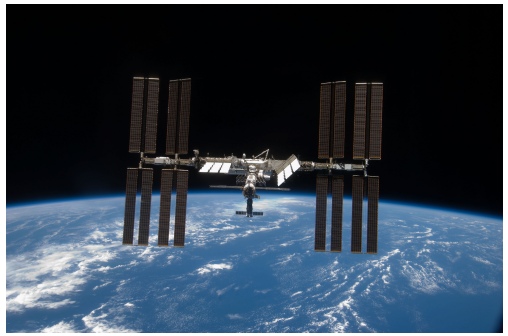
PHASE 3 Human Mars Orbit Capability

Mars Ascent

- LOX-Methane Propulsion
- ISRU (25 mT LOX)
- Cryo Propellant Storage (500 days)

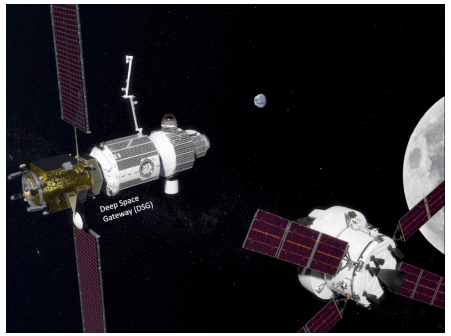
AES Activities by Exploration Phase

Phase 0: Exploration Systems Testing on ISS



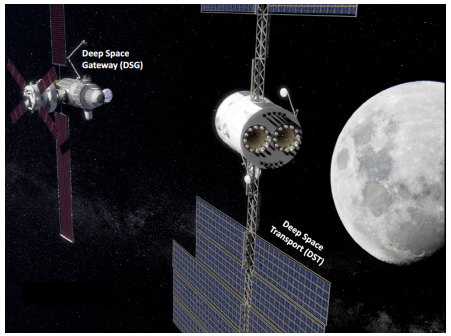
- Life Support Systems
- Spacecraft Fire Safety
- Radiation Safety
- Autonomous Mission Operations
- Logistics Reduction
- In-Space Manufacturing

Phase 1: Operating in the Lunar Vicinity



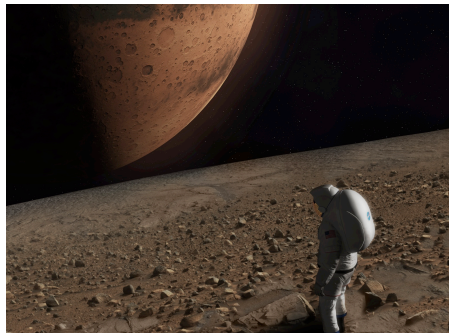
- Habitation
- Avionics, Software, & Communications
- Crew Module Systems
- Lander Technology
- EM-1 Secondary Payloads
- In-Situ Resource Utilization

Phase 2: Leaving the Earth-Moon System



- In-Space Power & Propulsion
- Deep Space Habitation Systems

Phases 3 & 4: Exploration in the Mars System



- Mars Robotic Precursors

DEEP SPACE HABITATION SYSTEMS

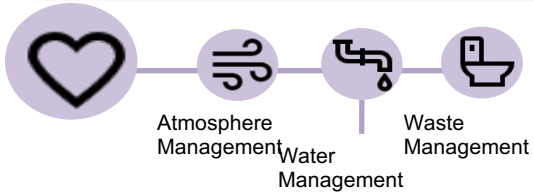
Habitation Systems Elements

TODAY Space Station

FUTURE Deep Space

LIFE SUPPORT

Excursions from Earth are possible with artificially produced breathing air, drinking water and other conditions for survival.

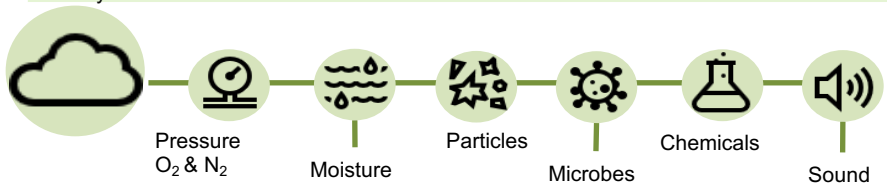


- 42% O_2 Recovery from CO_2
- 90% H_2O Recovery
- < 6 mo mean time before failure (for some components)

- 75%+ O_2 Recovery from CO_2
- 98%+ H_2O Recovery
- >30 mo mean time before failure

ENVIRONMENTAL MONITORING

NASA living spaces are designed with controls and integrity that ensure the comfort and safety of inhabitants.

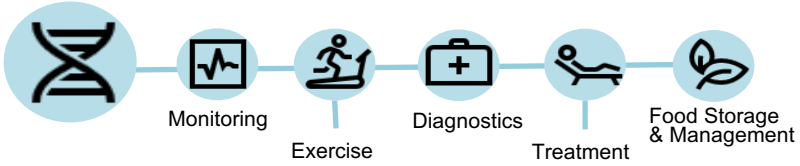


- Limited, crew-intensive on-board capability
- Reliance on sample return to Earth for analysis

- On-board analysis capability with no sample return
- Identify and quantify species and organisms in air & water

CREW HEALTH

Astronauts are provided tools to perform successfully while preserving their well-being and long-term health.

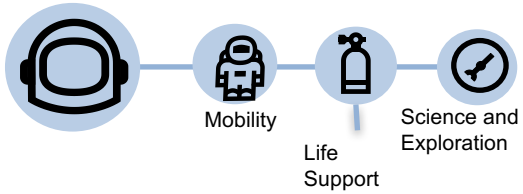


- Bulky fitness equipment
- Limited medical capability
- Frequent food system resupply

- Smaller, efficient equipment
- Onboard medical capability
- Long-duration food system

EVA: EXTRA-VEHICULAR ACTIVITY

Long-term exploration depends on the ability to physically investigate the unknown for resources and knowledge.



- High upper body mobility for limited sizing range
- Low interval between maintenance, contamination sensitive, and consumables limit EVA time
- Construction and repair focused tools; excessive inventory of unique tools

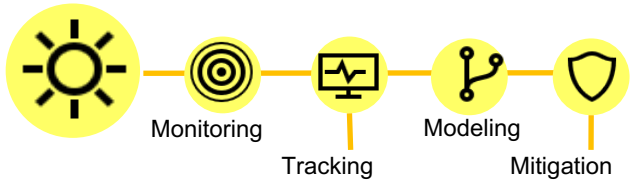
- Full body mobility for expanded sizing range
- Increased time between maintenance cycles, contamination resistant system, 25% increase in EVA time
- Geological sampling and surveying equipment; common generic tool kit

DEEP SPACE HABITATION SYSTEMS

Habitation Systems Elements

RADIATION PROTECTION

During each journey, radiation from the sun and other sources poses a significant threat to humans and spacecraft.



TODAY – Space Station

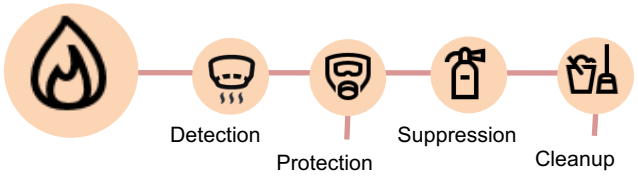
- Node 2 crew quarters (CQ) with polyethylene reduce impacts of proton irradiation.
- Large multi-layer detectors & small pixel detectors – real-time dosimetry, environment monitoring, tracking, model validation & verification
- Bulky gas-based detectors – real-time dosimetry
- Small solid-state crystal detectors – passive dosimetry (analyzed post-mission)

FUTURE – Deep Space

- Solar particle event storm shelter, optimized position of on-board materials and CQ
- Small distributed pixel detector systems – real-time dosimetry, environment monitoring, and tracking
- Small actively read-out detectors for crew – real-time dosimetry

FIRE SAFETY

Throughout every mission, NASA is committed to minimizing critical risks to human safety.



TODAY – Space Station

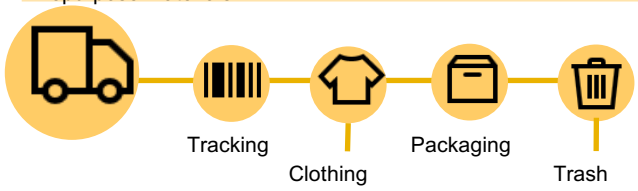
- Large CO_2 Suppressant Tanks
- 2-cartridge mask
- Obsolete combustion prod. sensor
- Only depress/repress clean-up

FUTURE – Deep Space

- Water Mist portable fire extinguisher
- Single Cartridge Mask
- Exploration combustion product monitor
- Smoke eater

LOGISTICS

Sustainable living outside of Earth requires explorers to reduce, recycle, reuse, and repurpose materials.



TODAY – Space Station

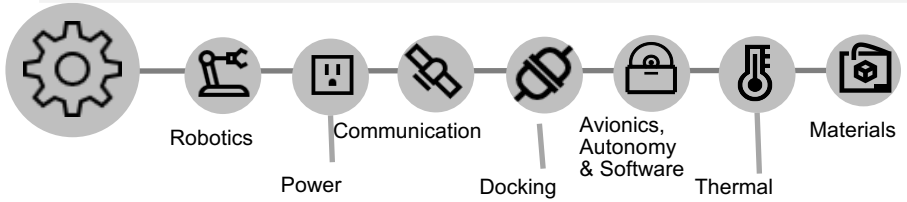
- Manual scans, displaced items
- Disposable cotton clothing
- Packaging disposed
- Bag and discard

FUTURE – Deep Space

- Automatic, autonomous RFID
- Long-wear clothing/laundry
- Bags/foam repurposed w/3-D printer
- Resource recovery, then disposal

CROSS-CUTTING

Powerful, efficient, and safe launch systems will protect and deliver crews and materials across new horizons.



TODAY – Space Station

- Minimal on-board autonomy
- Near-continuous ground-crew communications
- Some common interfaces, modules controlled separately

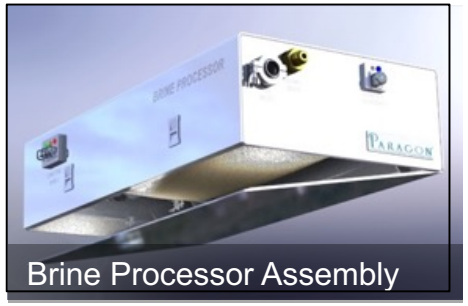
FUTURE – Deep Space

- Ops independent of Earth & crew
- Up to 40-minute comm delay
- Widespread common interfaces, modules/systems integrated
- Manufacture replacement parts in space

Life Support Systems

- **Aerosol Samplers**
  - Completed analysis of particle constituents for samples returned from ISS

- **Furthering Loop Closure on ISS**
  - Brine Processor Assembly: Recovers 98% of water from urine brine.
  - Plasma Pyrolysis Assembly (PPA): Recovers 90% of oxygen from CO_2

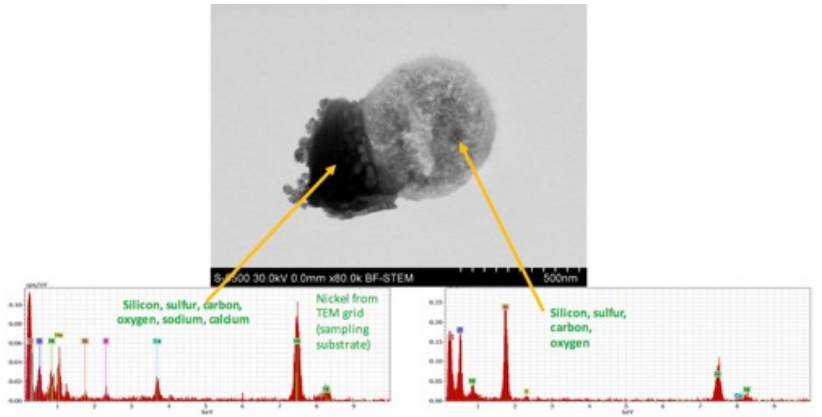


Brine Processor Assembly

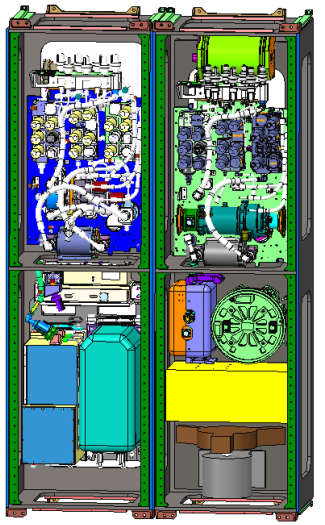

PPA Test Bed

- **NextSTEP ECLSS Activities**
  - Public-Private partnerships awarded under NextSTEP BAA
  - All Phase 2 contracts have been awarded and work is progressing.

Partner	Activity	Contract Signed	Kick-off Meeting
UTAS	Modular ECLSS	8/31/2017	9/18/17
Dynetics, Inc.	CO_2 scrubber	7/27/2017	8/18/2017
Sierra Nevada Corp.	Greenwall	9/21/2017	10/10/2017



Chemical analysis of aerosol particle


Sabatier / HPOGA ECLSS Pallets


Sierra Nevada Corp. Greenwall

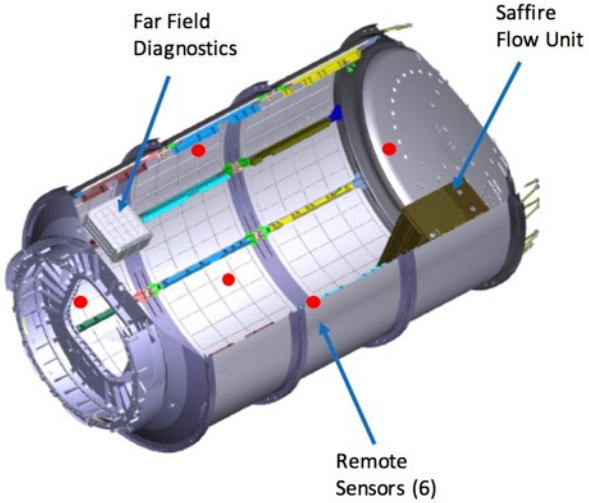
Spacecraft Fire Safety

- Saffire IV-VI flight experiments objectives:
  - Demonstrate fire monitoring and cleanup technologies in a realistic spacecraft environment
  - Characterize fire growth in high oxygen, low pressure atmospheres
  - Provide data to validate models of realistic spacecraft fire scenarios.

- Saffire IV-VI will be a technology demonstration for the Orion Anomaly Gas Analyzer (AGA) and Smoke-Eater post-fire cleanup canister.

- The Saffire IV-VI CDR was completed on August 2. The review board recommended that the Saffire Flow Unit should be tested at reduced pressure (0.5 atm). To conduct this test in a chamber would have significant cost and schedule impacts.

- Elevations about 14,000 feet yield pressures are 8.5 psia (~0.58 atm). The Saffire project took the Ground Development Unit to the top of Pikes Peak, Colorado to check flow uniformity and the flow control algorithm, and to verify fan performance.



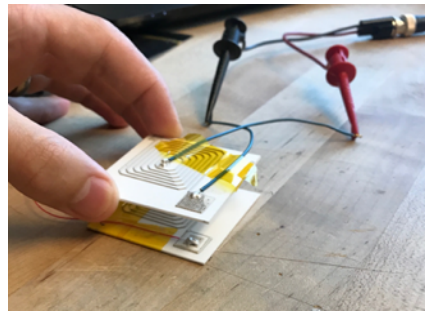
Saffire IV in Cygnus

Pikes Peak Summit

In-Space Manufacturing

- Multi-material Fab Lab BAA proposals were received on September 15. Selections are expected in November.
- Tethers Unlimited, Inc. 3-D printed several proof-of-concept urine funnels for potential use by the ISS crew. Recycling and sanitizing of the funnels was also demonstrated.
- MSFC 3-D printed a wireless humidity sensor and coupling antenna for ECLSS applications using conductive silver ink.
- The Ka-Band Objects Observation and Monitoring (KaBOOM) project 3-D printed a proof-of-concept 30 cm dish that could be scaled up to larger reflectors needed for deep space optical communications.

3-D printed urine funnels



3-D printed wireless humidity sensor

3-D printed reflector

NextSTEP Phase 2 Habitation Contract Status

Objectives

- NextSTEP-2 BAA contracts and discussions with International Partners will inform development of a Government Reference Architecture for the Deep Space Gateway.
- Ground testing of prototype habitats will assess human factors, subsystem integration, interoperability standards, and common interfaces.

Milestones

- Habitat prototypes delivered for testing – Dec 2018
- Habitat prototypes testing complete – Mar 2019

Contract Status

- Slow start due to funding limitations under Continuing Resolution, and negotiations to include ECLSS GFE and loan of Multi-Purpose Logistics Module hardware.
- Bigelow Aerospace contract still in negotiation due to Intellectual Property issues. Expect to sign in October.
- NanoRacks will present their final Phase 1 study report at HQ on November 1-2. Decision on Phase 2 to follow.

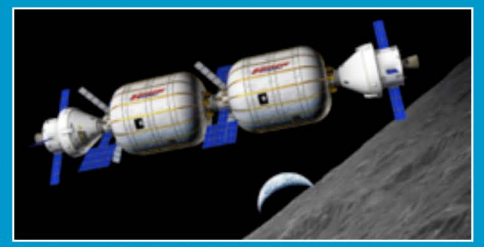
Partner	Contract Signed	Kick-off Meeting
Bigelow Aerospace	Contract not signed	TBD
Boeing	9/29/2017	10/24/2017
Lockheed Martin	6/30/2017	8/2/2017
NanoRacks	5/1/2017	5/24/2017
Orbital ATK	9/26/2017	10/30/2017
Sierra Nevada Corp.	8/29/2017	9/27/2017

NEXTSTEP HABITATION OVERVIEW

NextSTEP Phase 1: 2015-2016

Cislunar habitation concepts that leverage commercialization plans for LEO


LOCKHEED MARTIN


BIGELOW AEROSPACE


ORBITAL ATK


BOEING

FOUR SIGNIFICANTLY DIFFERENT CONCEPTS RECEIVED

Partners develop required deliverables, including concept descriptions with concept of operations, NextSTEP Phase 2 proposals, and statements of work.

NextSTEP Phase 2: 2016-2018

- Partners refine concepts and develop ground prototypes.
- NASA leads standards and common interfaces development.

FIVE GROUND PROTOTYPES BY 2018


BIGELOW AEROSPACE


BOEING


LOCKHEED MARTIN


SIERRA NEVADA CORPORATION


ORBITAL ATK

ONE CONCEPT STUDY


NANORACKS

Define reference habitat architecture in preparation for Phase 3.

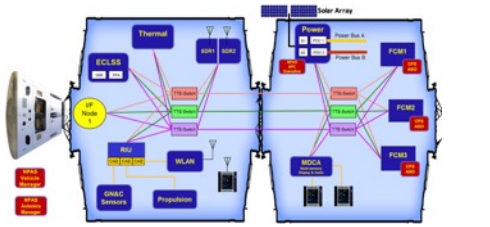
Initial discussions with international partners

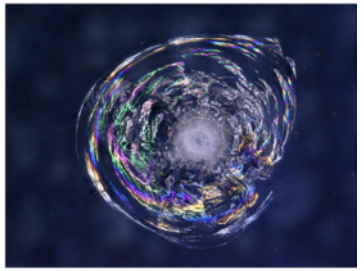
Phase 3: 2018+

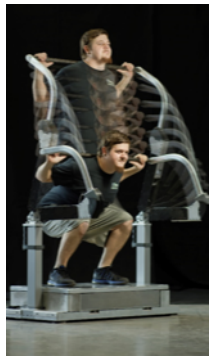
- Partnership and Acquisition approach, leveraging domestic and international capabilities
- Development of deep space habitation capabilities
- Deliverables: flight unit(s)

Crosscutting Government Furnished Equipment (GFE) for Prototype Habitats

- **Avionics:** Developing reference habitat avionics architecture that incorporates voting architecture and Time Triggered Ethernet among the standards.
- **ECLSS:** Developing simplified habitat ECLSS schematics to identify contractor provided and GFE elements.
- **Softgoods Testing:** Creep testing of restraint webbing, bladder material cold temperature testing, and softgoods analytical model development to better understand and model long-term behavior of expandable structures and human rating requirements.
- **Window Material Database:** Hypervelocity impact testing to characterize new lightweight materials such as Aluminum Oxynitride (ALON) to replace window glass.
- **Radiation Analyses**: Provide contractors with concepts for radiation mitigation and support their use of NASA radiation assessment tools to analyze habitat models.
- **Exercise Equipment:** Incorporate new, lighter weight exercise system concepts in habitat designs and ground testing activities.







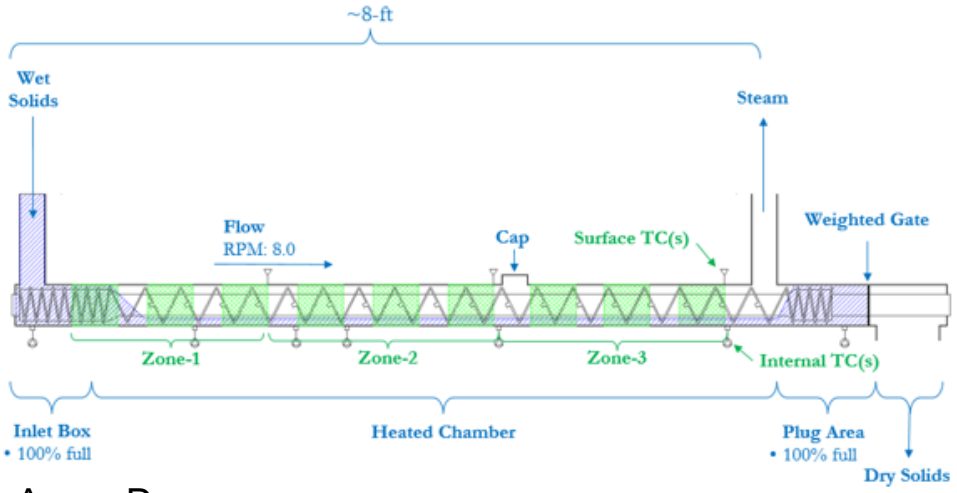
Ground Prototype Testing

- The NextSTEP Ground Test team successfully executed the first demonstration of a deep space gateway concept habitat mockup in the integrated Power, Avionics, and Software (iPAS) environment at JSC.
- A crew of four performed a representative activity timeline over eight hours, including exercise, medical procedures, lunar rover operations, and habitat logistics.
- The iPAS environment integrates the Avionics & Software architecture with modular power systems developed by AES.

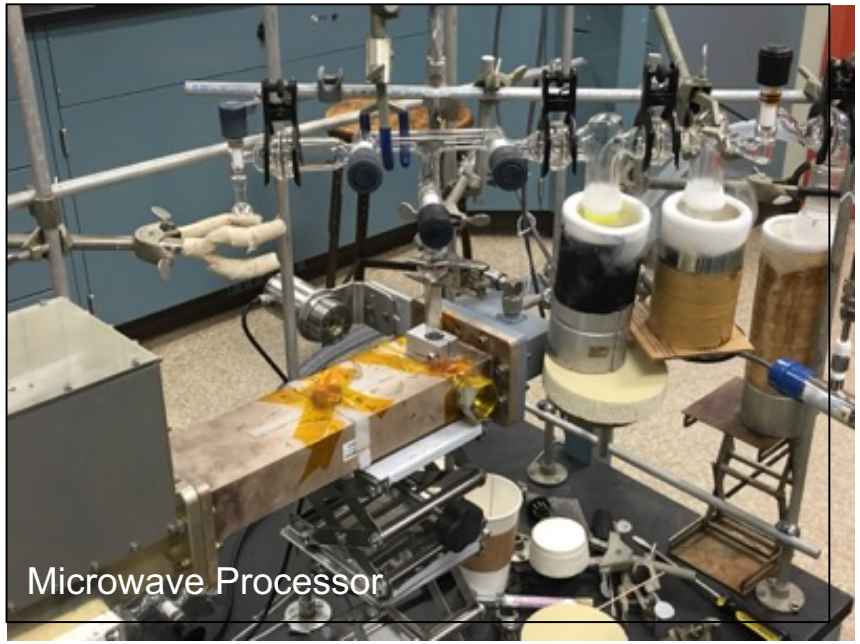
iPAS Mockup Habitat Test Bed

In-Situ Resource Utilization

- Tested designs for cryofreezers to acquire CO_2 from Mars atmosphere.
- Completed water mining trade study to determine the effects of Mars water resource types on excavation and processing system requirements:
  - Loose and compacted hydrated soils
  - Subsurface ice
- Competed design review for Auger Dryer concept for processing granular hydrated soils.
- Tested breadboard Microwave Processor and Open Air Dryer for extracting water from soil.
- Planning to issue NextSTEP BAA in the coming days to conduct trade studies and develop component technologies.



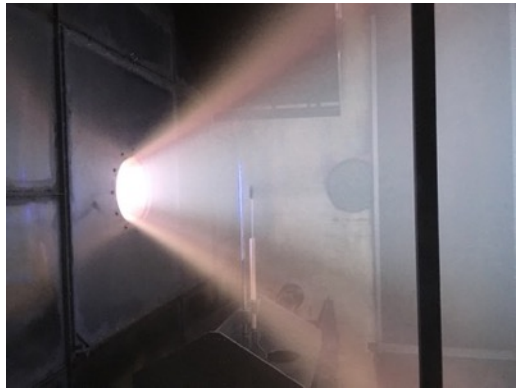
Auger Dryer



Microwave Processor

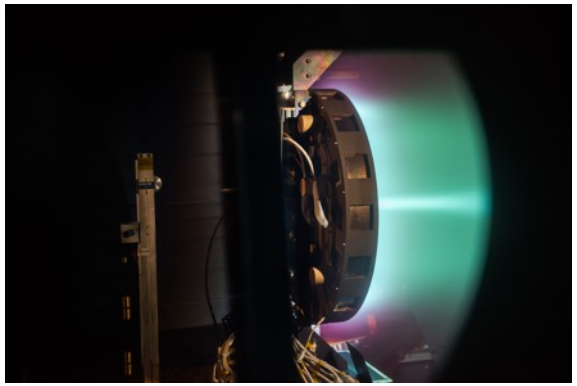
NextSTEP Advanced Propulsion

- NextSTEP 3-year partnerships to develop 100 kW electric thrusters and demonstrate continuous operation for 100 hours.
- Maturing technology for next generation in-space propulsion systems following initial demonstration of 40 kW solar electric propulsion system being developed by STMD.
- All three contracts completed their Year 1 milestones. Ad Astra has completed Year 2, and the other two are on track to complete Year 2 in 2017.



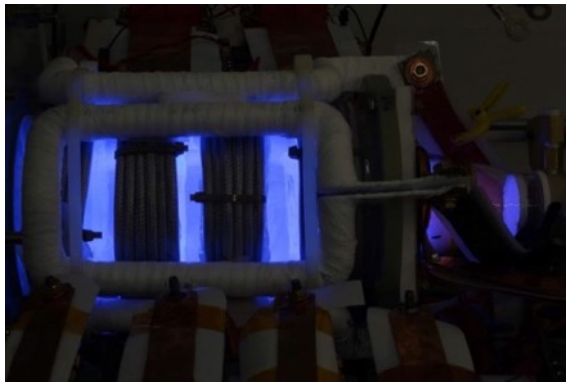
Ad Astra Rocket Company:
Variable Specific Impulse Magnetoplasma Rocket (VASIMR)

- FY17 Milestone: Complete 10 cumulative hours of thermal steady state operations.
- Completed 10 hours of cumulative VASIMR operations at 100 kW. Longest firing was three minutes.



Aerojet Rocketdyne: Nested Hall thruster

- FY17 Milestone: Test a 10 kW thruster integrated with PPUs and propellant feed system.
- Test has been delayed to mid-December due to upgrades of the vacuum chamber at the University of Michigan.
- Completed 100 kW risk reduction testing at GRC.



MSNW: Electrodeless Lorentz Force plasma thruster.

- FY17 Milestone: Demonstrate thermal steady state operations of PPUs with an inductive load.
- Test is expected to be completed in mid-November.

Mars Oxygen ISRU Experiment (MOXIE)

- Ceramatec - the company that is supplying the Solid Oxide Electrolysis (SOXE) stacks – was bought by a Canadian company that plans to shut down Ceramatec's operations in Utah. JPL has received 11 flight SOXE stacks and does not expect this loss of a key supplier will affect MOXIE payload integration and testing.

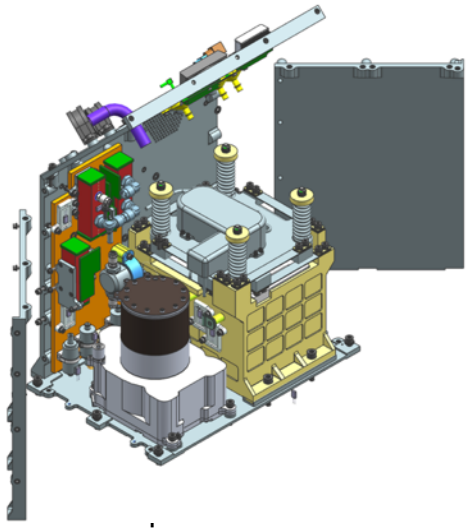
- The MOXIE scroll pump requires more power and its motor is operating at a higher temperature than predicted. A copper sleeve will be installed around the motor to conduct heat to the pump housing.

- Random current spikes have also been discovered during pump operation. The problem has been traced to friction in the pump bearings, which increases the pump power required to compress the Mars atmosphere. New bearings with greater radial play have been purchased.

- Completed over 450 hours of integrated testing with prototype SOXE stack, scroll pump, and SOXE drive electronics to validate experiment operation.

- The MOXIE electronics boards are still on the critical path. Engineering Model electronics have been fabricated and are being tested with flight software. The schedule margin for delivery of the flight hardware in October 2018 is currently 60 days.

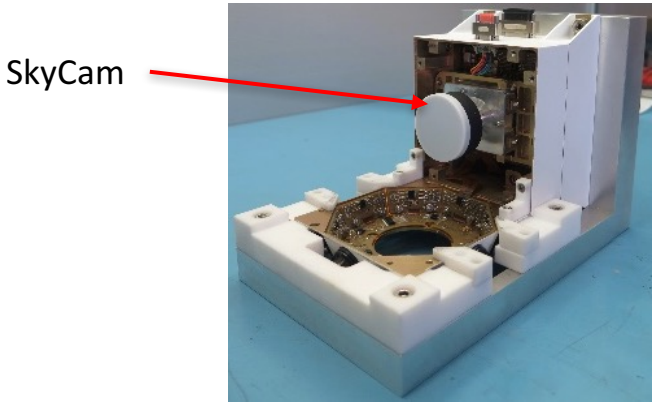
MOXIE test bed integrated system testing



MOXIE configuration

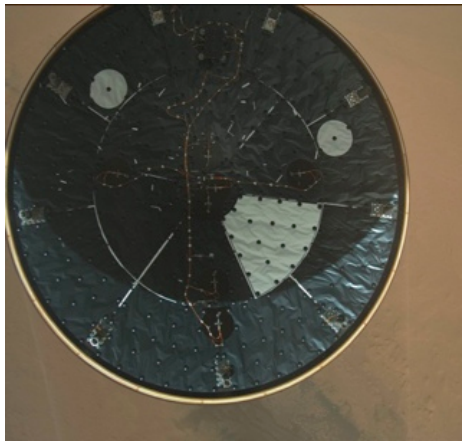
Mars 2020 Payloads: MEDA and MEDLI-2

- **Mars Environmental Dynamics Analyzer (MEDA)**
  - Surface weather station provided by Spain.
  - MEDA is currently about 3 weeks behind schedule for delivery of the flight hardware to JPL in July 2018. The critical path is the Instrument Control Unit and the wind sensors.
  - JPL is providing the SkyCam for the Radiation and Dust Sensor. Dust measurements will be used to investigate effects of dust on MOXIE performance.
  - Delivery of the SkyCam will be delayed to November due to problems with the Electrical Ground Support Equipment.



Radiation & Dust Sensor

- **Mars Entry, Descent, and Landing Instrumentation (MEDLI-2)**
  - MEDLI-2 complements and extends the MEDLI (MSL) measurements with additional heatshield observation locations, inclusion of supersonic aerodynamics, and backshell aerothermal and pressure observations.
  - Completed assembly, calibration, and environmental testing of supersonic pressure transducers.
  - Completed testing of Sensor Support Electronics (SSE) brassboard. SSE Engineering Development Unit will be delivered to Mars 2020 test bed in December.
  - Completed PDR on March 14-15.


MEDLI sensors on
MSL heat shield

EM-1 Secondary Payloads

- **BioSentinel (ARC):** Completed random vibration testing of spacecraft engineering model. Completed Phase 2 Safety Review. Radiation beam testing planned for October. Spacecraft integration will likely slip to December.

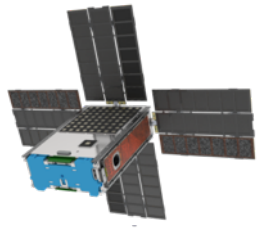
- **Lunar Flashlight (JPL):** Completed 100 mN thruster development testing. Space Dynamics Lab delivered Iris radio Engineering Development Unit to JPL.

- **NEA Scout (MSFC)**: Completed vibration and thermal vacuum testing of Active Mass Translator. Deployed solar sail engineering model. Spacecraft integration will likely slip to January.

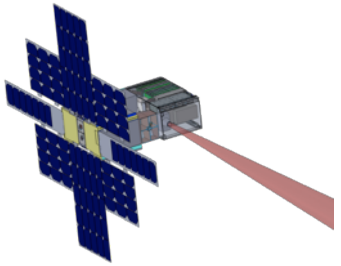
- **LunIR (Lockheed Martin)**: Procuring spacecraft bus from Tyvak. CDR completed in November.

- **Lunar IceCube (Morehead State University)**: Completed spacecraft bus and IR spectrometer designs. Tested Busek ion thruster with iodine propellant. Upgrading 21-meter antenna and demonstrated Disruption Tolerant Networking to communicate with EM-1 CubeSats. Delta CDR will likely slip to December.

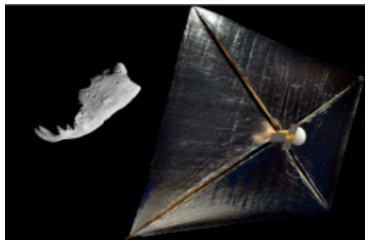
- **EM-1 Launch Delay:** CubeSats may be completed in Mid 2018 and stored for at least one year prior to launch. Planning activities to keep critical personnel and considering a change to the delivery dates.



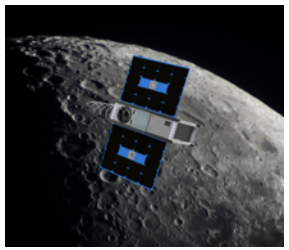
BioSentinel



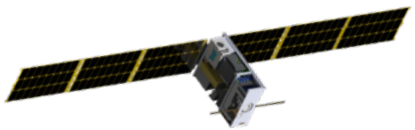
Lunar Flashlight



NEA Scout



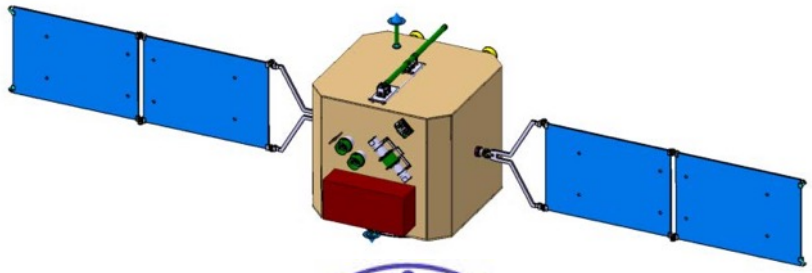
LunIR



Lunar IceCube

ShadowCam on KPLO

- Issued Announcement of Opportunity in September 2016 for NASA contributed instruments on Korea Pathfinder Lunar Orbiter (KPLO).

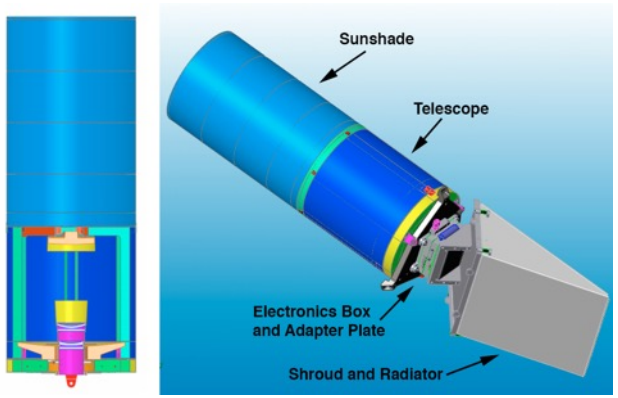


- Received 11 proposals in November 2016.

- Signed agreement in December 2016 with Korea Aerospace Research Institute (KARI) for hosting NASA instruments
  - KARI provides 15 kg payload mass in return for DSN support and assistance with lunar mission design and navigation

- Selected “ShadowCam” from Arizona State University and Malin Space Science Systems in April to image the Moon’s Permanently Shadowed Regions (PSR).

- With over 800 times the sensitivity of the LRO Narrow Angle Camera, ShadowCam will map the long hidden PSR topography and provide science data to address lunar Strategic Knowledge Gaps, lunar Decadal questions, and further our understanding of lunar volatiles.



ShadowCam

- Completed ShadowCam SRR in August. Completed KPLO PDR in September. KARI is procuring a launch vehicle for KPLO mission in December 2020.

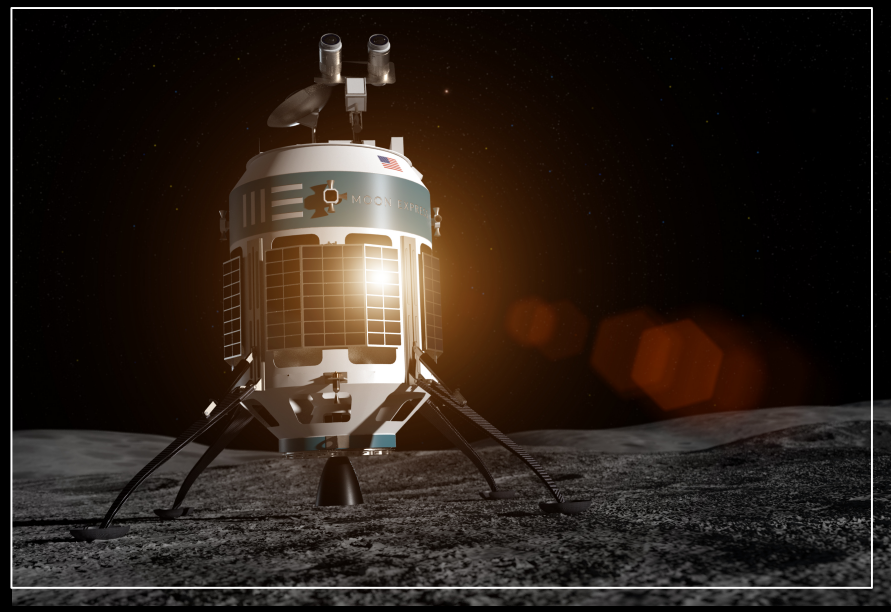
Lunar**CATALYST**

Lunar CArgo Transportation And Landing bY Soft Touchdown

In 2014, NASA competitively selected U.S. private-sector partners, based on likelihood of successfully fielding a commercially-viable lunar surface cargo transportation capability. Agreements renewed in 2017 for two more years.

Masten Space Systems

Moon Express



Astrobotic Technologies

HELPING U.S. INUDSTRY PARTNERS TO

LOWER RISKS | CONDUCT TEST | ACCELERATE VEHICLE DEVELOPMENT TO LAUNCH

Lander Technology

Lunar CATALYST

- Extending Space Act Agreements by two years to continue NASA technical support until commercial landers are ready to fly in 2018-2020.
- Astrobotic Technology, Inc. completed PDR for their Peregrine lunar lander.
- Masten Space Systems tested main engine and assembled structure for terrestrial demonstrator.
- Moon Express is planning to test their bipropellant rocket engine at the Plum Brook B2 facility in the coming months.
- AES is planning to issue RFP for Commercial Lunar Payload Services in collaboration with SMD.

Moon Express plans to fly their MX-1E lander in 2018.

Lander Technology

- Frontier Aerospace completed risk reduction testing of the 100-lbf thrust Deep Space Engine (DSE-100) under a Phase III SBIR contract. The DSE-100 uses MON-25/MMH propellants and is capable of operating at low temperatures.

DSE-100 testing

Resource Prospector

First Mining Mission on Another World

- Characterize the nature and distribution of water/volatiles in lunar polar sub-surface materials
- Demonstrate ISRU processing of lunar regolith

Student Engagement and Outreach Activities

- **CubeSat Launch Initiative:** Released Announcement of Opportunity on August 3. Selections are expected in February 2018. Completed ”CubeSats 101” document to guide new CubeSat developers.

- **SPHERES:** Supported the Zero Robotics Middle School Challenge final competition on August 11. Thirteen schools competed to program the SPHERES free flyers on ISS. National Geographic filmed the competitions to include in a documentary**.**

- **NASA Imagery Experts:** Supported NASA TV coverage of the total solar eclipse on August 21 from hub in Charleston, SC. Live video was broadcast from an aircraft and sites across the country.

- **6th Future Engineers Challenge:** The “Two for the Crew” Challenge to design a 3-D print that combines the functions of two pieces of ISS equipment into one kicked off on September 21 at the National Air and Space Museum. The winning part will be manufactured on the ISS Additive Manufacturing Facility.

- **RASC-ALs:** Released announcement of RASC-ALs 2018 competition for design projects covering human exploration topics that is open to undergraduate and graduate university-level students studying fields with applications to human space exploration. Received 62 notices of intent.

Summary

- AES is using the NextSTEP public-private partnerships to develop prototype cislunar habitats, habitation systems, and lunar lander capabilities

- AES is developing ISS flight experiments to demonstrate advanced life support and environmental monitoring systems that are relevant to future human spaceflight system such as those required for the Deep Space Gateway and Transport concepts.

- AES is developing five CubeSats for launch on EM-1 to address Strategic Knowledge Gaps including those critical to understanding lunar volatiles

- 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.