National Aeronautics and Space Administration

HEOMD's Advanced Exploration Systems

Status Update

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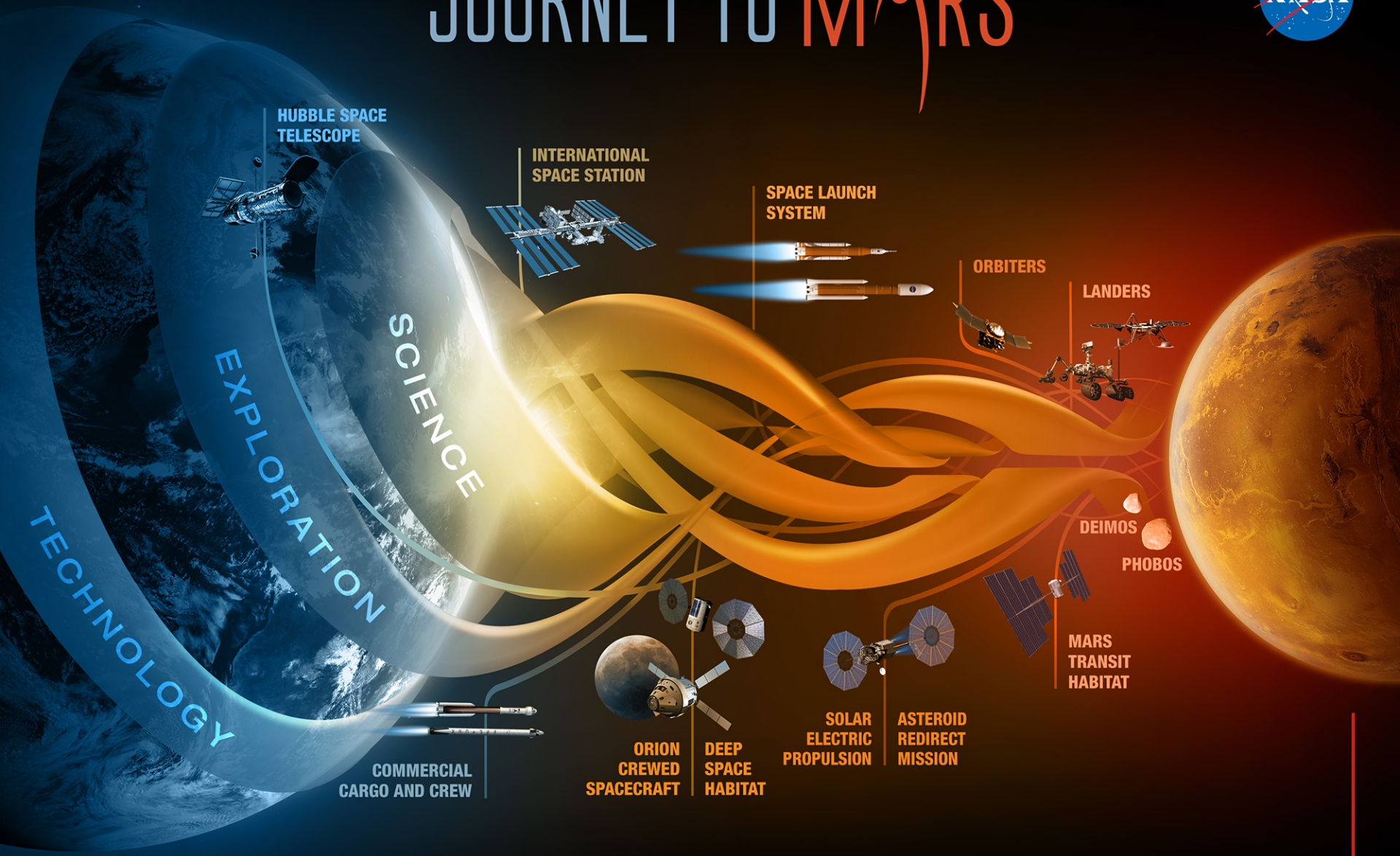
Human Exploration and Operations Mission Directorate

November 4, 2015

JOURNEY TO MARS



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.

Summary for FY15

- AES had established 72 milestones for FY15
- Over 60% include flight demonstration elements
- Goal was to achieve at least 80% - For FY15 AES accomplished 56 of 72 - 78%
- AES includes 572 civil servants and 162 contractors in FY15

Demand Areas for Pioneering Space: Steps on the Journey to Mars

	Mission / Demand Areas	ISS	Cis-lunar Short Stay (e.g. ARM)	Cis-lunar Long Stay	Cis-Mars Robotic	Orbital Proving Ground	Mars Operational
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		Initial Short Duration	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	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

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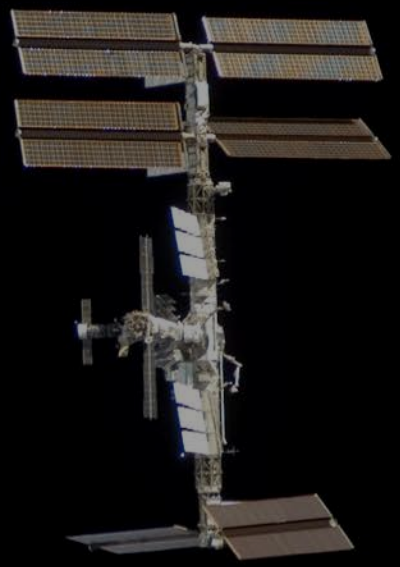
NEAR-TERM OBJECTIVES

DEVELOP AND VALIDATE EXPLORATION CAPABILITIES IN AN IN-SPACE ENVIRONMENT

- Long duration, deep space habitation systems
- Next generation space suit
- Autonomous operations
- Communications with increased delay
- Human and robotic mission operations
- Operations with reduced logistics capability
- Integrated exploration hardware testing



LONG-DURATION HUMAN HEALTH EVALUATION

- Evaluate mitigation techniques for crew health and performance in micro-g space environment
- Acclimation from zero-g to low-g

COMMERCIAL CREW TRANSPORTATION

- Acquire routine U.S. crew transportation to LEO

PROVING GROUND OBJECTIVES

Enabling Human Missions to Mars

TRANSPORTATION

- **Heavy Launch Capability**: beyond low-Earth orbit launch capabilities for crew, co-manifested payloads, large cargo
- **Crew**: transport at least four crew to cislunar space
- **In-Space Propulsion**: send crew and cargo on Mars-class mission durations and distances

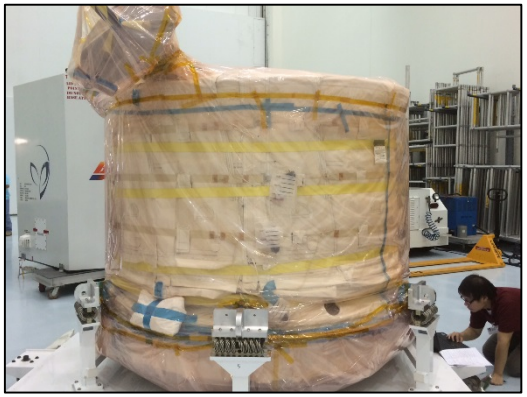
WORKING IN SPACE

- **ISRU**: Understand the nature and distribution of volatiles and extraction techniques and decide on their potential use in human exploration architecture.
- **Deep-space operations capabilities**: EVA, Staging, Logistics, Human-robotic integration, Autonomous operations
- **Science**: enable science community objectives

STAYING HEALTHY

- **Deep-Space Habitation**: beyond low-Earth orbit habitation systems sufficient to support at least four crew on Mars-class mission durations and dormancy
- **Crew Health**: Validate crew health, performance and mitigation protocols for Mars-class missions

AES RECENT ACCOMPLISHMENTS

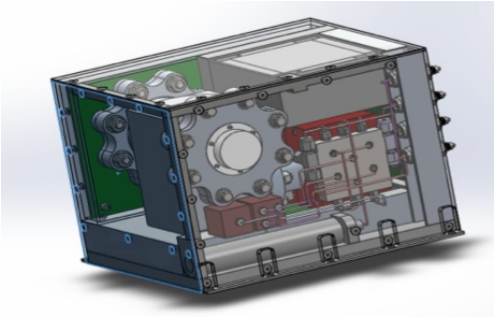


BEAM: Delivered flight hardware to KSC for launch on SpaceX-8 NET January 2016.

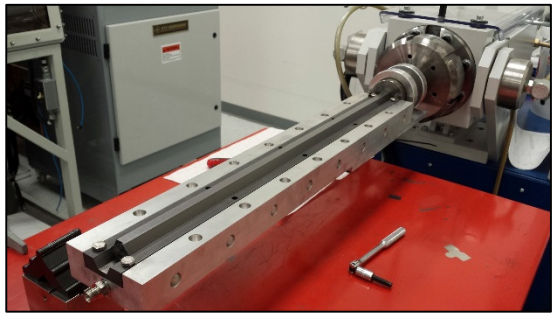
Logistics Reduction: Delivered Multi-Purpose Cargo Transfer Bag for demo on ISS. Bag will be repurposed to provide acoustic insulation of treadmill noise.

Spacecraft Fire Safety: Completed System Acceptance Review for the Saffire-I, II, and III flight experiments. Saffire-I will be launched on the Orb-5 mission in March 2016.

Resource Prospector: Completed field test of prototype rover and RESOLVE sample analysis payload in JSC rock yard.



Life Support Systems: Completed Systems Requirements Review for Spacecraft Atmosphere Monitor. ISS demo planned in 2018.



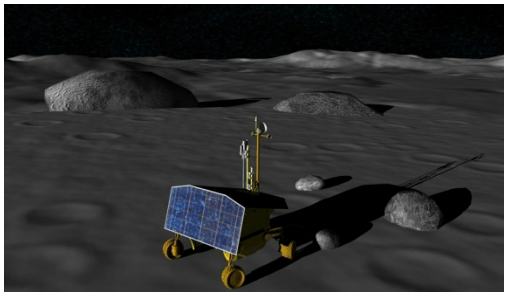
Nuclear Thermal Propulsion: Fabricated graphite composite fuel element and tested in 2800K hot hydrogen flow.

In-Situ Resource Utilization

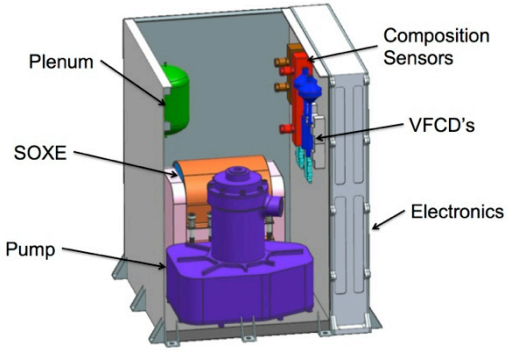
- **Objectives**
  - Reduce logistical support from Earth by utilizing local resources to produce water, oxygen, propellants, and other consumables.

- **Current Activities**
  - **Resource Prospector**: Formulating robotic mission to prospect for ice and other volatiles in polar regions of the Moon.
  - **Mars Oxygen ISRU Experiment (MOXIE)**: Demonstration of oxygen production from the Mars atmosphere on the Mars 2020 mission. Co-funded with STMD.

- **Accomplishments**
  - **Resource Prospector**: Completed field test of prototype rover and sampling payload. Initiating joint study with Taiwan to develop concepts for lunar lander.
  - **MOXIE:** Adopting Tiger Team recommendations for design changes to address mass, power, and cost growth.



Resource Prospector



MOXIE

Prototype rover for Resource Prospector

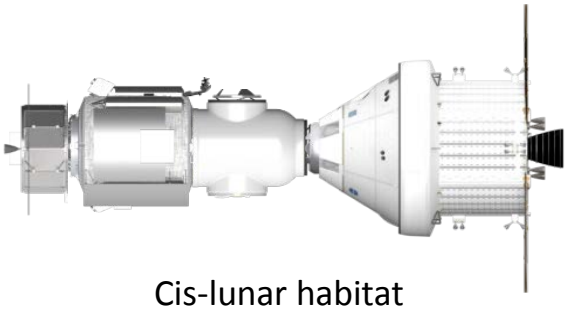
Habitation

- **Objectives**
  - Develop a deep space habitat that will enable a crew to live in deep space on missions lasting 1,100 days.

- **Current Activities**
  - **Bigelow Expandable Activity Module (BEAM)**: Demonstration of inflatable habitat on ISS. Launch on SpaceX-8 planned in January.
  - **Next Space Technology Exploration Partnerships (NextSTEP):** Commercial partnerships to develop concepts for cis-lunar habitats that are extensible to Mars transit habitats.

- **Accomplishments**
  - **BEAM:** Flight hardware delivered to KSC.
  - **NextSTEP Commercial Habitat Concept Studies:** Awarded contracts to Bigelow Aerospace, Boeing, Lockheed Martin, and Orbital ATK.

BEAM flight hardware



Cis-lunar habitat

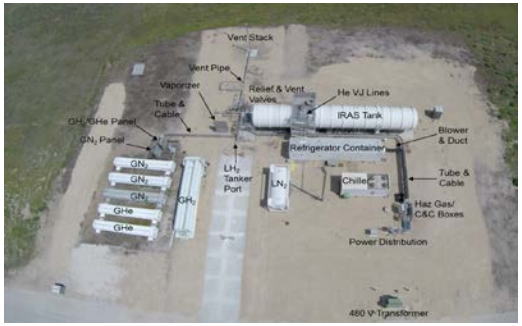
Autonomous Ops

- **Objectives**
  - Reduce the crew's dependence on ground-based mission control.
  - Automate ground operations to reduce cost.

- **Current Activities**
  - **Autonomous Systems & Operations**: Developing software tools for vehicle systems monitoring and fault diagnosis, automated scheduling of maintenance tasks, and automated procedure execution. Demonstrating capabilities on Orion and ISS.
  - **Automated Propellant Loading**: Demonstrating autonomous fueling of launch vehicles with cryogenic propellants.

- **Accomplishments**
  - **Autonomous Systems & Operations:** Demonstrated advanced caution and warning system for Orion power system on EFT-1.
  - **Automated Propellant Loading**: Demonstrated automated LOX and LH2 loading

Crew-centric mission ops



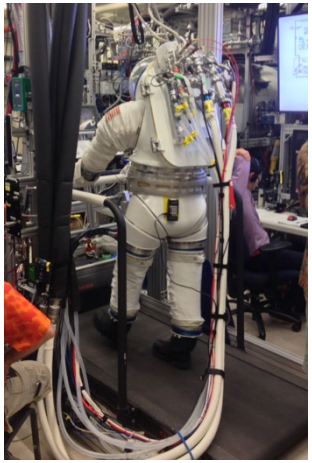
Automated Propellant Loading

Exploration EVA

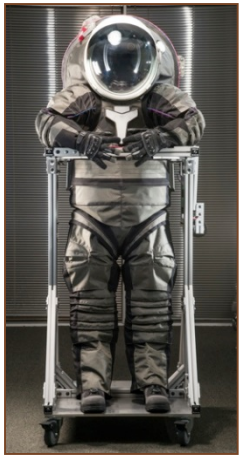
- **Objectives**
  - Enable the crew to conduct “hands-on” surface exploration and in-space operations.
  - Demonstrate advanced space suit on ISS.

- **Current Activities**
  - **Portable Life Support System (PLSS)**: Developing next generation PLSS with new technology components for carbon dioxide removal, pressure regulation, thermal control, and energy storage.
  - **Z-Suit:** Developing advanced space suit with improved mobility for surface exploration.

- **Accomplishments:**
  - **PLSS:** Completed human-in-the-loop testing.



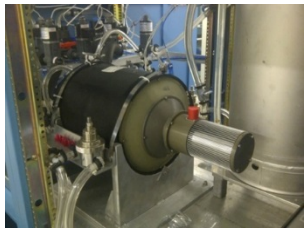
Human-in-the-loop testing of PLSS 2.0



Z-2 suit

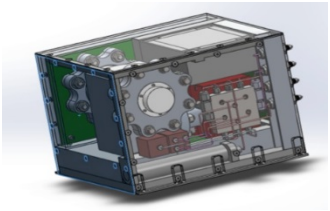
Environmental Control & Life Support

- **Objectives**
  - Develop highly-reliable life support systems that recycle air, water, and waste to reduce consumables.
  - Demonstrate next generation life support systems with integrated ground-based testing and ISS flight experiments.

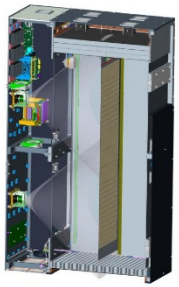


Cascade Distillation System

- **Current Activities**
  - **Life Support Systems:** Developing improved sorbents for CO_2 removal, High Pressure Oxygen Generation system for replenishing space suits, Cascade Distillation System for waste water processing, and Spacecraft Atmosphere Monitor for detecting trace gas contaminants in ISS air.
  - **Spacecraft Fire Safety:** Saffire experiments will investigate the spread of fires in microgravity. Also developing technologies for fire suppression, combustion products monitoring, and post fire clean-up.
  - **Next Space Technology Exploration Partnerships (NextSTEP):** Developing advanced CO_2 removal technologies, modular ECLSS, and hybrid biological and chemical life support systems.



Spacecraft Atmosphere Monitor



Saffire Fire Safety Experiment

- **Accomplishments**
  - **Life Support Systems**: Completed SRR and Phase 0/1 safety reviews for Spacecraft Atmosphere Monitor.
  - **Spacecraft Fire Safety**: Completed assembly & environmental tests of 3 flight units
  - **NextSTEP ECLSS Studies**: Awarded contracts to Dynetics, Orbitec, and UTC.

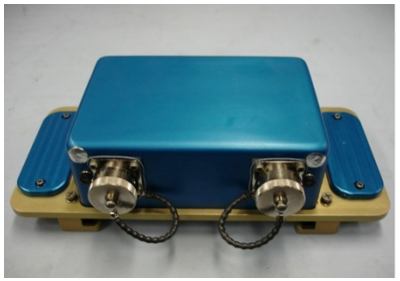
Radiation Safety

- **Objectives**
  - Characterize the radiation environments of potential destinations for human exploration.
  - Understand the biological effects of space radiation.
  - Develop shielding and countermeasures to protect crew from harmful space radiation.

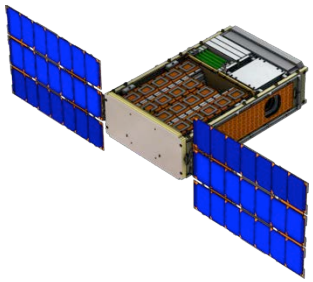
- **Current Activities**
  - **Radiation Sensors:** Measuring radiation environments on Orion, ISS, and Mars surface.
  - **BioSentinel:** CubeSat that will investigate the effects of deep space radiation environment on yeast DNA.

- **Accomplishments**
  - **Radiation Sensors:** Completed EFT-1 demonstration and PDR for EM-1 sensors and completed another year of operations with RAD at Mars.
  - **BioSentinel:** Completed payload PDR.

Radiation Assessment Detector on MSL



Radiation Environment Monitor flown on EFT-1



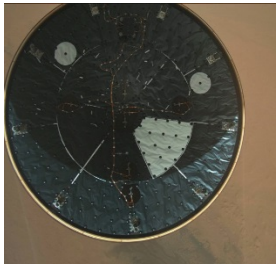
BioSentinel CubeSat

Entry, Descent, & Landing (EDL)

- **Objectives**
  - Develop the capability to land heavy payloads (> 18 mt) on Mars for human missions.

- **Current Activities**
  - **Mars Entry, Descent, & Landing Instrumentation (MEDLI-2):** Measuring temperatures and pressures on Mars 2020 heat shield to validate aerothermal models. Co-funded with STMD.
  - **Lander Technology**: Developing autonomous precision landing and LOX-methane propulsion technology.
  - **Lunar CATALYST:** Space Act Agreements with Astrobotic Technologies, Moon Express, and Masten Space Systems to stimulate commercial payload delivery services to lunar surface.

- **Accomplishments:**
  - **MEDLI-2**: Completed SRR.
  - **Lander Technology**: Tested LOX-methane engine. Completed ALHAT testing.
  - **Lunar CATALYST**: Astrobotics completed end-to-end mission simulation; Moon Express completed tether test of lander; Masten Space Systems complete propulsion system PDR.



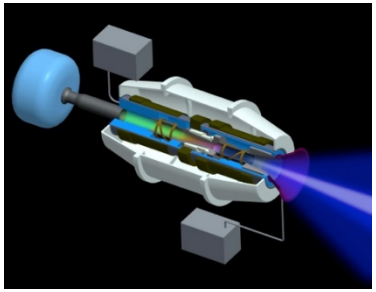
MEDLI

Navigation Doppler Lidar

Astrobotic Technologies lander

In-Space Power & Propulsion

- **Objectives**
  - Develop 100 kW-class solar electric propulsion systems for transporting cargo to Mars.
  - Develop technologies for nuclear thermal propulsion to enable rapid transport of crew to Mars.
  - Develop high energy, modular power systems for exploration missions.



Variable Specific Impulse Magnetoplasma Rocket (VASIMR)

- **Current Activities**
  - **Next Space Technologies Exploration Partnerships (NextSTEP):** Developing 100 kW electric propulsion systems and testing for 100 continuous hours.
  - **Nuclear Thermal Propulsion**: Developing fuel elements, reactor concepts, and affordable ground testing methods. Transferring project to STMD.
  - **Modular Power Systems**: Developing high energy density batteries for EVA, fuel cells for SLS, and power distribution units for habitats.

Testing NTP fuel element

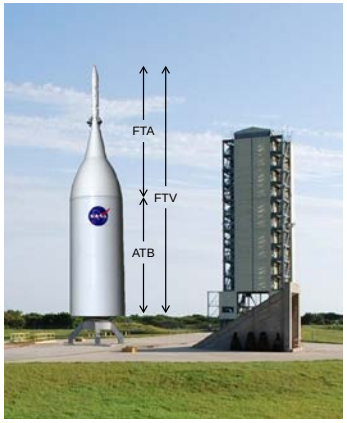
- **Accomplishments**
  - **NextSTEP High Power Electric Propulsion**: Awarded contracts to Ad Astra, Aerojet Rocketdyne, and MSNW.
  - **Nuclear Thermal Propulsion:** Fabricated and tested graphite composite fuel element in 2800K hot hydrogen flow.
  - **Modular Power Systems**: Delivered EVA battery and power distribution unit for habitat test bed.

Beyond LEO: SLS & Orion

- **Objectives**
  - Support development of the integrated transportation system for enabling human missions beyond Earth orbit.

- **Current Activities**
  - **Ascent Abort Test (AA-2):** Flight test to demonstrate high altitude, high speed abort for Orion crew capsule in 2019. AES is providing workforce for in-house integration of test vehicle.
  - **Avionics and Software**: Integrated testing of avionics architectures and certification of Core Flight Software for use on the Orion.

- **Accomplishments**
  - **Avionics & Software**: Certified Core Flight Software for human missions and demonstrated on Orion backup computer.



AA-2 flight test

Communications

- **Objectives**
  - Develop high-data rate communications infrastructure to support deep space missions.

- **Current Activities**
  - **Ka-Band Objects Observation & Monitoring (KaBOOM):** Demonstrating antenna arrays with atmospheric disturbance compensation for future space communications and radar applications. Co-funded by DoD.
  - **Disruption Tolerant Networking (DTN):** Infusion of store and forward communications protocols into NASA and international missions.

KaBOOM at KSC

- **Accomplishments**
  - **KaBOOM:** Demonstrated uplink arraying and atmospheric compensation at X-band with DSN antennas. Planning to install two new antennas at KSC and upgrade to radar array.
  - **DTN:** Demonstrated supervisory control of ESA Eurobot from ISS using DTN.Agreement with KARI to conduct DTN experiments.

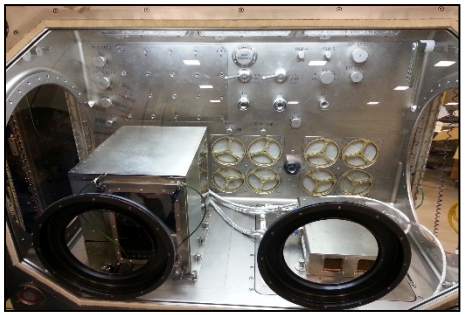
Logistics Reduction

- **Objectives**
  - Reduce the mass of logistics that must be resupplied from Earth by repurposing packaging materials, processing waste, manufacturing parts and producing food in space.

- **Current Activities**
  - **Logistics Reduction**: Demonstration of autonomous inventory management on ISS and development of a Universal Waste Management System for Orion.
  - **In-Space Manufacturing**: Demonstration of 3D printing of spare parts and tools on ISS.
  - **Synthetic Biology Applications**: Using genetically engineered bacteria to produce bionutrients to supplement the crew's diet.

- **Accomplishments**
  - **Logistics Reduction**: Delivered Multi-Purpose Cargo Transfer Bag and assembled Heat Melt Compactor. Demonstrated extended wear clothing on ISS.
  - **In-Space Manufacturing:** Demonstrated 3D printer to fabricate parts on ISS. Completed post-flight testing of printed parts.
  - **Synthetic Biology Applications**: Demonstrated that genetically modified microorganisms can be grown in edible media for food production.

Multi-Purpose Cargo Transfer Bag



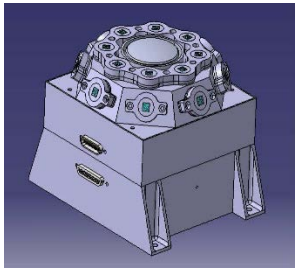
3D printer on ISS

Robotic Precursors

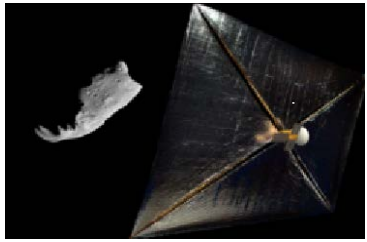
- **Objectives**
  - Gather crucial data on environments, hazards, and the availability of resources at potential destinations to inform the design of exploration systems.

- **Current Activities**
  - **Mars Environmental Dynamics Analyzer (MEDA)**: Surface weather station on Mars 2020 rover. Co-funded by STMD.
  - **Lunar Flashlight:** EM-1 secondary payload to search for volatiles in shadowed lunar craters
  - **NEA Scout:** EM-1 secondary payload using a solar sail to fly by a near-Earth asteroid**.**
  - **Lunar IceCube:** EM-1 secondary payload for detecting lunar volatiles**.** NextSTEP partnership with Morehead State University.
  - **Skyfire:** EM-1 secondary payload to test remote sensing and rendezvous technologies. NextSTEP partnership with Lockheed Martin.
  - **Solar System Exploration Research Virtual Institute (SSERVI)**: Funds research on moon and small bodies to support exploration and science objectives.

- **Accomplishments**
  - **MEDA:** Completed Instrument Accommodation Review.
  - **NEA Scout:** Completed SLS Phase 0/1 Safety Review.
  - **Lunar Flashlight**: Redesigned spacecraft to use chemical propulsion and lasers to illuminate lunar craters instead of solar sail.
  - **SSERVI**: Held 2015 Exploration Science Forum.



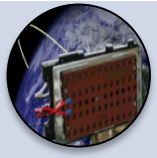
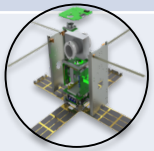
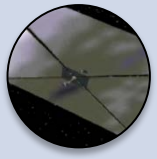
MEDA dust sensor



NEA Scout

AES EM-1 Secondary Payload Overview

- **HEOMD's Advanced Exploration Systems (AES) selected 3 concepts for further refinement toward a combined Mission Concept Review (MCR) and System Requirements Review (SRR) completed in August 2014**
  - All projects are proceeding towards Phase B design
- **Primary selection criteria:**
  - Relevance to Space Exploration Strategic Knowledge Gaps (SKGs)
  - Life cycle cost
  - Synergistic use of previously demonstrated technologies
  - Optimal use of available civil servant workforce
- **Completed a Non-Advocate Review of the Science Plan**

Payload *NASA Centers*	**Strategic Knowledge Gaps Addressed**	**Mission Concept**
BioSentinel ***ARC**/JSC* 	**Human health/performance in high-radiation space environments** • Fundamental effects on biological systems of ionizing radiation in space environments	Study radiation-induced DNA damage of live organisms in cislunar space; correlate with measurements on ISS and Earth
Lunar Flashlight ***JPL**/MSFC* 	**Lunar resource potential** • Quantity and distribution of water and other volatiles in lunar cold traps	Locate ice deposits in the Moon's permanently shadowed craters
Near Earth Asteroid (NEA) Scout ***MSFC**/JPL* 	**Human NEA mission target identification** • NEA size, rotation state (rate/pole position) **How to work on and interact with NEA surface** • NEA surface mechanical properties	Flyby/rendezvous and characterize one NEA that is representative of a potential human mission target

BioSentinel

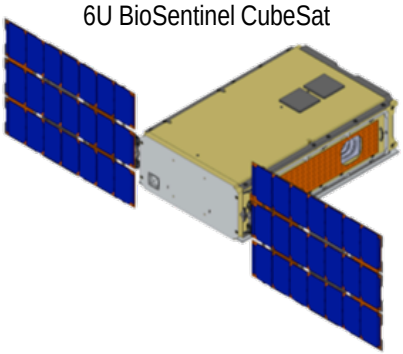
WHY BioSentinel?

- Effect of space radiation environment (GCR's, protons, & Solar Particle Event (SPE)) in conjunction with varied gravity levels has not been systematically studied
- The BioSentinel Payload will use a yeast radiation biosensor to gauge the genetic (DNA) damage and repair caused by space radiation.

LEVERAGES:

- CubeSat expertise (GeneSat, PharmaSat, SporeSat) to build the payload
- Current investment in miniaturized radiation monitoring (REM medipix radiation LET spectrometer)
- Synergies with NEA Scout and Lunar Flashlight (Communication system, Attitude Determination & Control System)

6U BioSentinel CubeSat



BioSensor Dev Card (1 of 18)

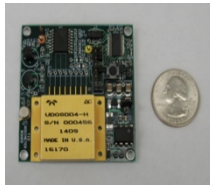
MEASUREMENTS: *Radiation biosensor payload measures DNA damage response to deep space radiation in living cells (BioSentinel yeast strain responds to Double Strand Breaks)*

- Correlate biosensor with on-board Linear Energy Transfer (LET) and Total Ionizing Dose (TID) radiation detectors

Key Technical Constraints:

- 6U CubeSat containing 3U BioSensor, 1U radiation spectrometer & dosimeter, <10 W average payload power, and identical BioSentinel payload for ISS and ground control

LET Spectrometer Dev Board



TID Dosimeter Dev Board

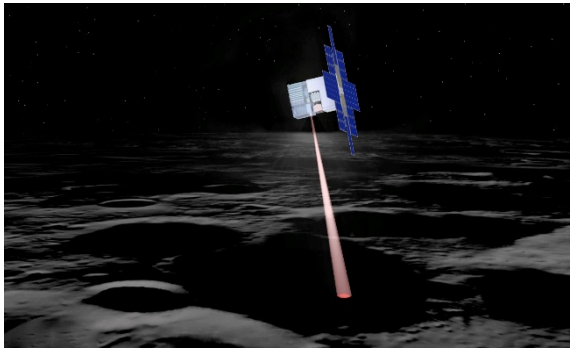
Lunar Flashlight

WHY Lunar Flashlight?

- Look for surface ice deposits and identify favorable locations for in-situ utilization
- Recent robotic mission data (Mini RF, LCROSS) strongly suggest the presence of ice deposits in Permanently Shadowed Regions.
- Locations where Diviner measures the coldest year-round temperatures also have anomalous reflectivity in LOLA and LAMP data, suggesting water frost
- SKG Understand the quantity and distribution of water and other volatiles in lunar cold traps

LEVERAGES:

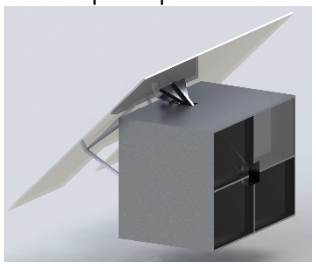
- CubeSat developments and standards (INSPIRE, Morehead State University & Industry experience)
- Synergies with NEA Scout (CubeSat bus, communication system, integration & test and operations, are in review)



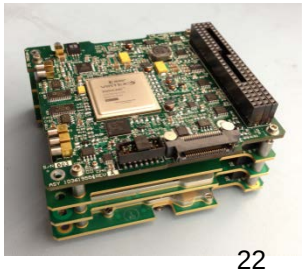
MEASUREMENTS: *Lunar ices (water, methane, ammonia) on permanently shadowed regions (PSR)*

- Four separate 50-75 watt pulsed Lasers illuminate 1Km^2 of the Lunar surface and define the 4 spectral bands of interest.
- 2 channel near IR spectrometer detects the reflected light from 1-2-μm at an altitude of 20Km.

JPL point spectrometer



JPL X-Band IRIS Radio



Key Technical Constraints:

- 6U Cubesat with 290m/s ΔV Green Propellant system, 40W/1Kw EPS, deployer compatibility and optimized cost.

Near Earth Asteroid (NEA) Scout

WHY NEA Scout?

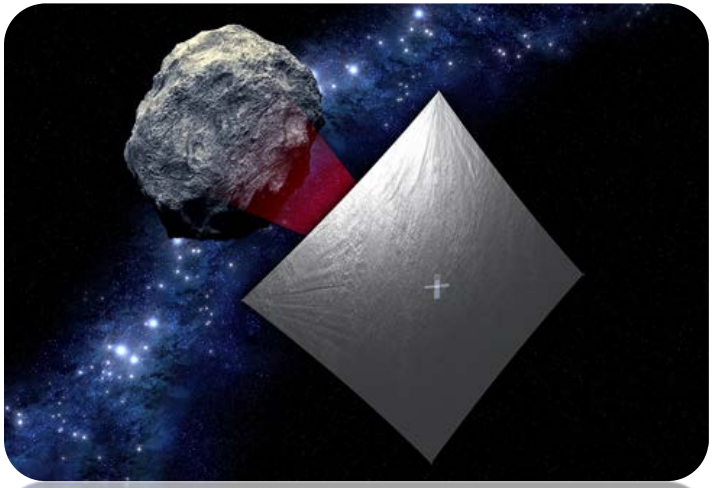
- Characterize a NEA with an imager to address key Strategic Knowledge Gaps (SKGs)
- Demonstrates low cost reconnaissance capability for HEOMD (6U CubeSat)

LEVERAGES:

- Solar sail development expertise (NanoSail-D, Solar Sail Demonstration Project, LightSail-1)
- CubeSat developments and standards (INSPIRE, University & Industry experience)
- Synergies with Lunar Flashlight (Cubesat bus, communication system, integration & test)

MEASUREMENTS: *NEA volume, spectral type, spin mode and orbital properties, address key physical and regolith mechanical SKG*

- ≥80% surface coverage imaging at ≤50 cm/px
- Spectral range: 400-900 nm (incl. 4 color channels)
- ≥30% surface coverage imaging at ≤10 cm/px



Key Technical Constraints:

- 6U Cubesat and ~85 m^2 sail, expected dispenser compatibility and optimize cost
- Target must be within ~1.0 AU distance from Earth due to telecom limitations
- Slow flyby with target-relative navigation on close approach

SUMMARY FOR FY16

- AES establishing 73 milestones for FY16
- Over 60% include flight demonstration elements
- Goal is to achieve at least 80%
- AES includes 382 civil servants and 133 contractors in FY16

AES - FY16 Activities

- **In-Situ Resource Utilization**
  - Resource Prospector (ARC)
  - Mars Oxygen ISRU Experiment (MOXIE) (JPL)

- **Habitation**
  - Bigelow Expandable Activity Module (BEAM) (JSC)
  - NextSTEP Commercial Habitat Studies (JSC)
  - Docking Hatch (JSC)

- **Autonomous Operations**
  - Autonomous Systems & Operations (ARC)
  - Automated Propellant Loading (KSC)

- **Exploration EVA**
  - Advanced Space Suit (JSC)

- **Environmental Control & Life Support**
  - Life Support Systems (MSFC)
  - Spacecraft Fire Safety (GRC)
  - NextSTEP ECLSS Studies (MSFC)

- **Radiation Safety**
  - Radiation Sensors (JSC)
  - BioSentinel (EM-1 Secondary Payload) (ARC)

- **Entry, Descent, and Landing**
  - Mars EDL Instrumentation (MEDLI-2) (LaRC)
  - Lander Technology/Lunar CATALYST (MSFC)

- **In-Space Power and Propulsion**
  - NextSTEP High Power Electric Propulsion (GRC, JSC)
  - Modular Power Systems (GRC)

- **Crew Module Systems**
  - Ascent Abort-2 Test (JSC)
  - Avionics & Software (JSC)

- **Communications**
  - Ka-Band Objects Observation & Monitoring (KaBOOM) (KSC)
  - Disruption Tolerant Networking (JSC)

- **Logistics Reduction**
  - Logistics Reduction & Repurposing (JSC)
    - Universal Waste Management System (JSC)
  - In-Space Manufacturing (MSFC)
  - Synthetic Biology Applications (ARC)

- **Robotic Precursors**
  - EM-1 Secondary Payloads (Lunar Flashlight, NEA Scout)
  - NextSTEP Small Spacecraft (Lunar IceCube, Skyfire)
  - Mars Environmental Dynamics Analyzer (MEDA)
  - Solar System Exploration Research Virtual Institute (SSERVI)

- **Strategic Operations, Integration and Study Activities**
  - GER 3 development (ISECG) (JSC, LaRC)
  - Evolvable Mars Campaign / Human Architecture Team and Innovative studies (JSC, LaRC)
  - System Maturation Teams (LaRC, JSC)

MAFOR FY16 MILESTONES

- **Jan 2016** **BEAM:** Launch to ISS (NET)
- **Jan 2016** **Mars 2020:** MOXIE Preliminary Design Review
- **Mar 2016** **Spacecraft Fire Safety:** Saffire-I flight experiment launch (NET)
- **Apr 2016** **Resource Prospector**: Complete lunar lander study with Taiwan
- **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
- **Aug 2016** **NextSTEP Adv. Prop.**: Complete subsystems for VASIMR test article
- **Sep 2016** **Advanced Space Suit:** Human vacuum testing of Z-2 suit
- **Sep 2016** **Mars 2020:** MOXIE Critical Design Review
- **Sep 2016** **NextSTEP Habitation:** Complete habitat system concept studies**.**

FY 2016 Budget Scenarios

	FY15 Final Amount	Request	House	Senate	Year CR	Proposed
ERD	$ 320.5	$ 399.2	$ 350.0	$ 321.2	$ 306.4	$ 335.6
HRP	$ 142.0	$ 167.8	$ 147.1	$ 89.9	$ 127.9	$ 142.0
ARM	$ 7.6	$ 38.0	$ 33.3	$ 37.9	$ 14.1	$ 23.1
AES	$ 170.9	$ 193.4	$ 169.6	$ 193.4	$ 164.4	$ 170.5
Labor	$ 85.0	$ 58.6	$ 61.1	$ 61.1	$ 61.1	$ 61.1
Travel	$ 1.5	$ 1.4	$ 1.4	$ 1.4	$ 1.4	$ 1.4
Procurement	$ 84.4	$ 133.3	$ 107.1	$ 130.9	$ 101.9	$ 108.0

Program Execution Approach:

- **Start FY16 by executing at $170.5M**

NextSTEP BAA Overview

- **Solicited three critical areas for technology maturation:**
  - Advanced Propulsion Systems
  - Habitation Systems (Including Life Support)
  - Small Satellite Missions (EM-1 secondary payloads)

- **Facilitates development of deep space human exploration capabilities in the cislunar proving ground and beyond**
- **Continues successful public-private partnership model and spurs commercial endeavors in space**
- **Selected 12 proposals and will proceed to enter into *Fixed Price Contracts* with technical/payment milestones with private-sector partners**
  - Emphasis for eligibility and execution placed on contribution of private corporate resources to the private-public partnership to achieve goals and objectives
  - Selected partners with the technical capability to mature key technologies and demonstrate commitment toward potential commercial application

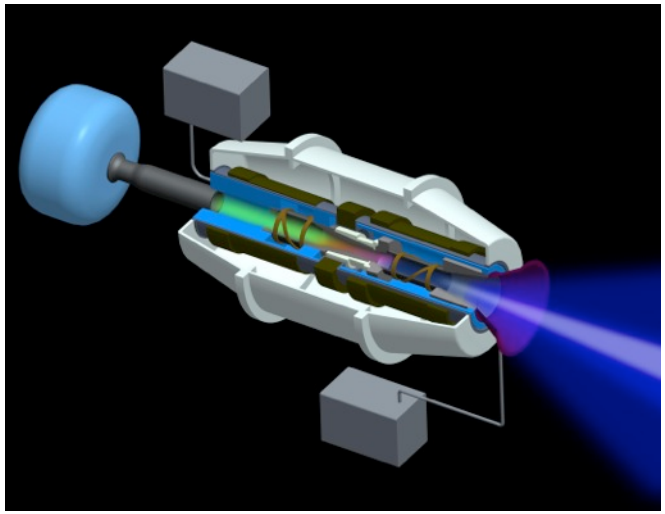
NextSTEP Contract Award Summary

Contract	Award Date	PoP (End Date)
Ad Astra	8/7/2015	8/6/2018 (with 2, 1-yr options)
MSNW	9/17/2015	9/16/2018 (with 2, 1-yr options)
Aerojet Rocketdyne	TBD (Nov)	12 mo base w/ 2, 1-yr options. In negotiations. Estimate award late Nov.
Dynetics	8/10/2015	8/9/2016
Hamilton Sundstrand	9/8/2015	9/7/2016
Orbital Technologies	9/4/2015	9/3/2016
Bigelow Aerospace	7/31/2015	7/30/2016
Boeing	TBD (Nov)	1 year. Final negotiations. Estimate award early Nov.
Lockheed Martin	9/23/2015	9/22/2016
Orbital ATK	9/3/2015	9/2/2016
Lockheed Martin SkyFire	TBD (Nov)	In final negotiations, then final review. Estimate award early Nov.
Morehead SU Lunar IceCube	TBD (Nov)	11 mo w/3 options. In Final review. Planned award 2 Nov.

NextSTEP BAA: Three Advanced Propulsion Awards

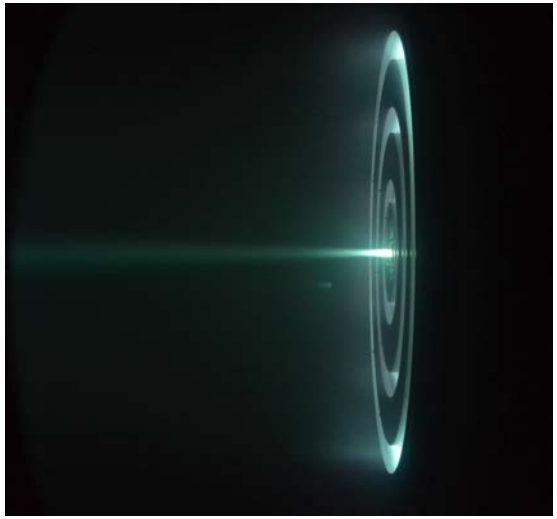
Developing propulsion technology systems in the 50- to 300-kW range to meet the needs of a variety of deep-space mission concepts beyond capabilities currently being developed for ARM SEP

Ad Astra Rocket Company
Webster, Texas



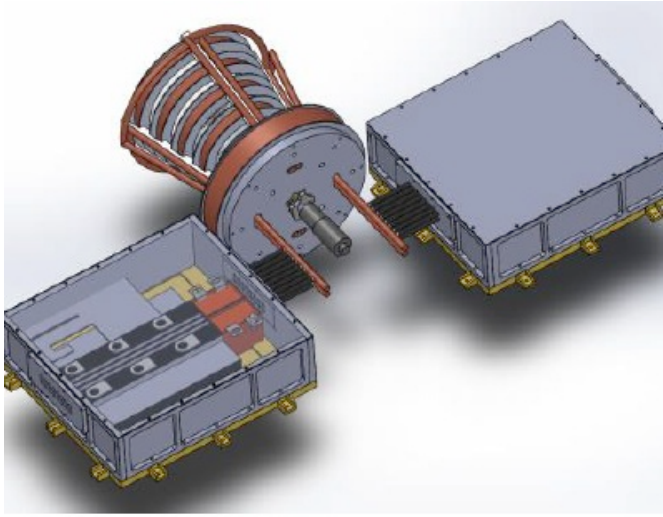
Thermal Steady State Testing of a VASIMR Rocket Core with Scalability to Human Spaceflight

Aerojet Rocketdyne Inc.
Redmond, Washington



Operational Demonstration of a 100 kW Electric Propulsion System with 250 kW Nested Hall Thruster

MSNW LLC,
Redmond, Washington



Flexible High Power Electric Propulsion for Exploration Class Missions

Each was selected to develop and demonstrate advanced electric (EP) systems using fixed-priced, milestone achievement based contracts over three years.

NextSTEP BAA: Three Advanced Propulsion Awards

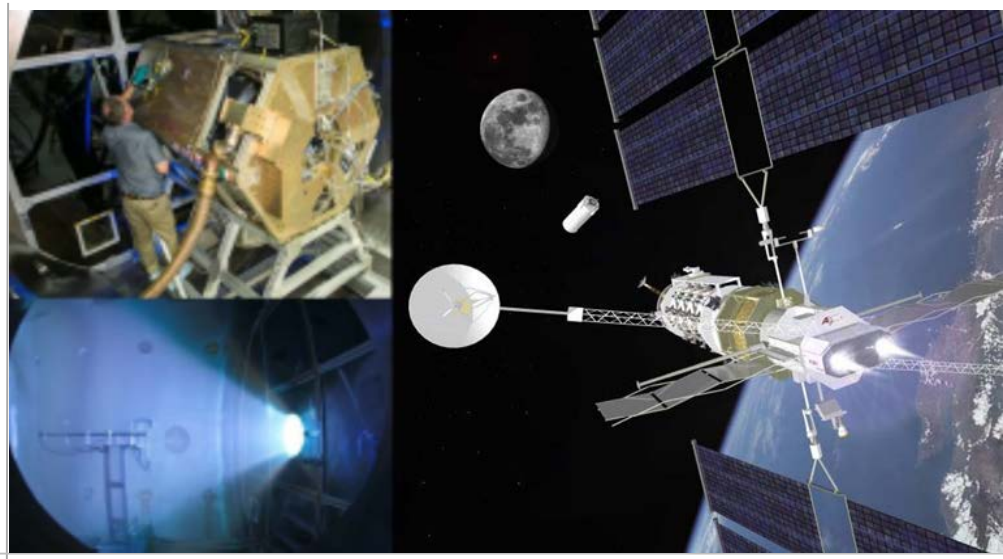
In the third year, each contractor's EP system (thrusters, PPUs, internal thermal control systems, propellant mgmt. systems) will demonstrate a minimum of 100 hours of continuous operations at power levels of at least 100 kWs in a relevant TRL 5 environment.

- **NextSTEP BAA Advanced EP Performance Goals:**
  - Broad specific impulse range (2,000 to 5,000s)
  - Operational end-to-end total system efficiency > 60%
  - In-space lifetime capability > 50,000 hours
  - Operational (thrusting) capability > 10,000 hours
  - Total flight propulsion system specific mass < 5kg/kW
  - Design of EP engine extensible to continuous operations at 200 to 300 kW
  - EP engine scalable to MW levels

Thermal Steady State Testing of a VASIMR® Rocket Core with Scalability to Human Spaceflight

Objectives & Technical Approach:

- Demonstrate a TRL-5 single core VASIMR® thruster with PPUs, the VX-200SS, in thermal steady-state for at least 100 continuous hours at 100 kW
- Leverage Ad Astra's privately funded superconducting magnet, propellant management system, power processing units, and unique vacuum capabilities to test the steady-state performance of its integrated thermal design



Team:

- Dr. F.R. Chang Díaz, Ad Astra, CEO, Strategic Guidance, Private Investment Leveraging

Key team members, organization, and role

- Dr. M.D. Carter, Ad Astra, Engineering Development and Principal Investigator
- Dr. J.P. Squire, Ad Astra, Experimental Implementation and Measurement, co-Principal Investigator
- Mr. L. Dean, Ad Astra, Director of Manufacturing
- Mr. R.E. Greene, Ad Astra, Contracts Manager

Schedule

Milestones	Year 1	Year 2	Year 3
System Design Mfg & Assembly			
1st Stage, 2nd Stage pulsed Low-T plasma tests			
2nd Stage & Plasma Dump Preparation Complete			
1st & 2nd Stage Integrated Low-T plasma tests			
VX-200SSTM Integrated Duration High-T plasma tests			

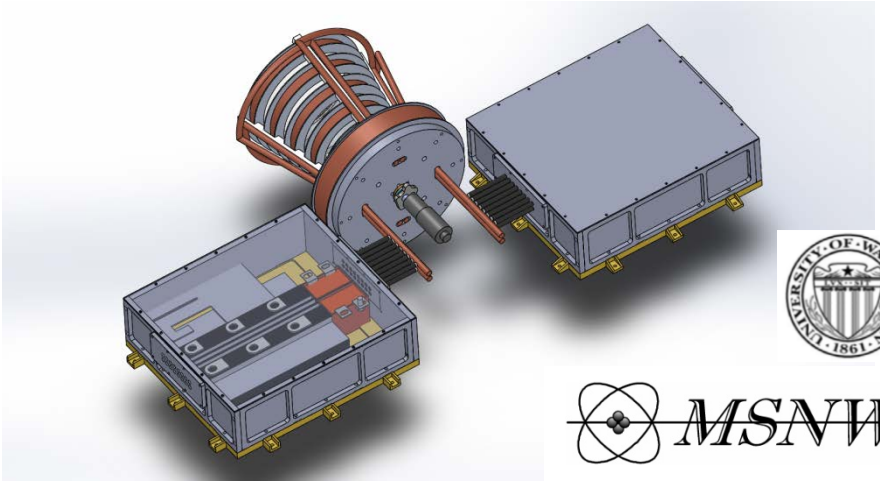
Cost

- Total cost to NASA: $9,060,564
- Ad Astra Cost Sharing: $11,786,257

Flexible High Power Electric Propulsion for Exploration Class Missions

100 Joule Electrodeless Lorentz Force Thruster

- Lightweight, highly variable, highly scalable EP thruster
- One Thruster, 250 mm diameter
  - 1,500-8,000 s Isp
  - 100-1000 kW input power
- ELF-250 electromagnetically forms, accelerates and ejects a high-density magnetized plasmoid – no electrodes
- Operation on Water, Argon, Xenon, and other propellants
- Science & Technology demonstrated in the laboratory
  - Multi-Pulse and complex propellants demonstrated
  - 0.1-2K Joule, 100 W -2 MW discharges demonstrated



Team:

- MSNW LLC
  - Design high power thruster geometry
  - Design and qualify PPU
  - Thermal design and modeling
- University of Washington
  - Build and operate high power facility
  - Operate ELF-250 at 100 kW for 100 hrs
- Helion Energy Inc
  - Design and implement advanced, lightweight PPU systems

Schedule

6 months – Thruster Assembly
12 Months - Pulsed operation 100 kW thruster and PPU
15 months – Full thermal engineering model
24 months – Steady thermo-vac thruster and PPU operations
27 months – Pulsed High power facility upgrades completed
36 months - 100 hr, 100-200 kW integrated test

Cost

- Total Government contribution $1,500,000
MSNW with subcontracts
- Total cost sharing $1,500,000
Cost sharing MSNW IR&D, UW Facilities, and Helion Energy PPU Development

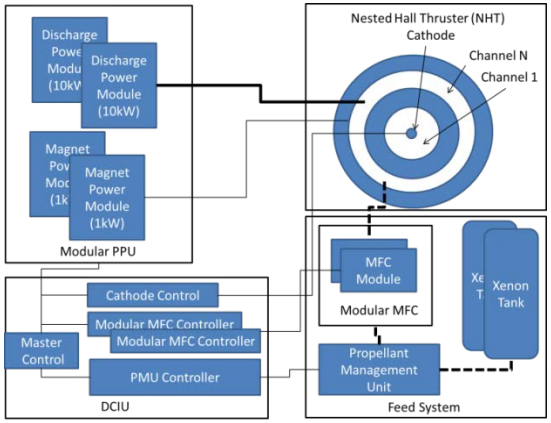
OPERATIONAL DEMONSTRATION OF A 100 KW ELECTRIC PROPULSION SYSTEM WITH 250 KW NESTED HALL THRUSTER

Objectives & Technical Approach:

- Demonstrate performance capabilities to TRL 5 with 100 kW input power for 100 h at thermal steady-state
- Implement the XR-250, 250 kW Hall thruster
- Demonstrate the XR-100, 100 kW system extensible to MW class systems

Metric	XR 100 Objective
Specific Impulse	~2,000 to ~5,000 s
In space lifetime capability	>50,000 h
Operational lifetime capability	>10,000 h
System efficiency	>60%
Power per thruster	250 kW
System kg/kW	<5 kg/kW

Image:



Team:

- Propulsion System Development: Aerojet Rocketdyne
- Propulsion System Testing: NASA GRC
- Feed System: Aerojet Rocketdyne
- PPU Engineering: Aerojet Rocketdyne
- PPU Fabrication: STS
- Thruster Development:
  - Aerojet Rocketdyne
  - University of Michigan
  - Jet Propulsion Laboratory

Schedule

- Year 1: Component demonstration testing
- Year 2: TRL 4 System Demonstration Test
- Year 3: TRL 5 System Demonstration Test

Cost

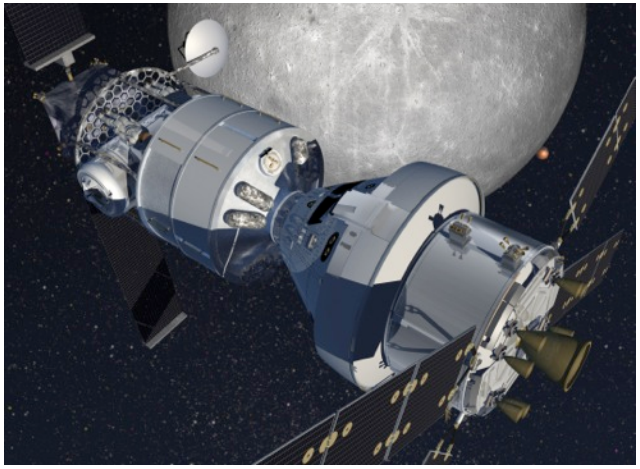
- Aerojet Rocketdyne Contract: $6,273,767*
- Government Direct Funding
  - GRC: $986,000
  - JPL: $722,000
- Team Corporate Contribution: $11,958,694

* Exact amount subject to final negotiations

NextSTEP BAA: Seven Habitation Awards (1 of 3)

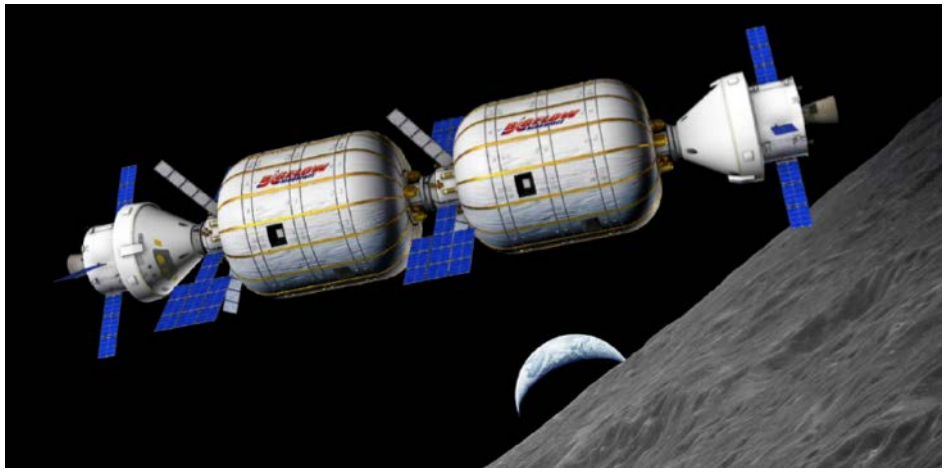
NASA awarded seven habitation projects. Four will address habitat concept development, and three will address Environmental Control and Life Support Systems (ECLSS)

Lockheed Martin
Denver, CO



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 LLC
Las Vegas, NV

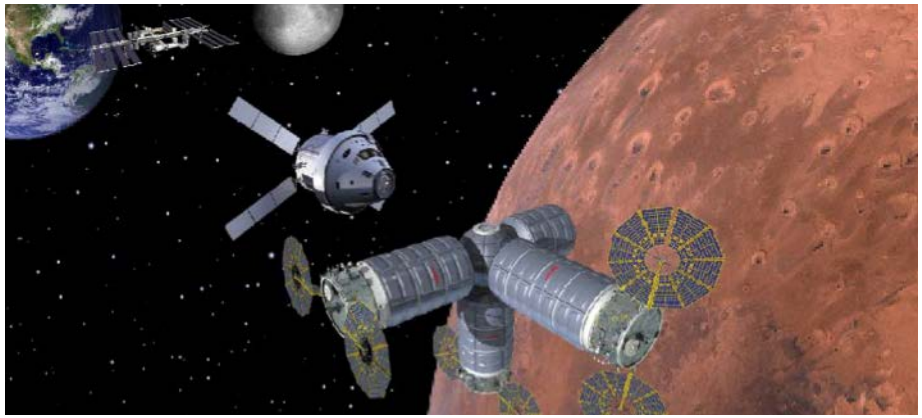


The B330 for deep-space habitation will support operations/missions in LEO, DRO, and beyond cislunar space

NextSTEP BAA Habitation Awards (2 of 3)

NASA awarded seven habitation projects. Four will address habitat concept development, and three will address Environmental Control and Life Support Systems (ECLSS)

Orbital ATK
Dulles, VA



Habitat that employs a modular, building block approach that leverages the Cygnus spacecraft to expand cislunar and long duration deep space transit habitation capabilities and technologies

Boeing
Houston, TX

Developing a simple, low cost habitat that is affordable early on, allowing various technologies to be tested over time, and that is capable of evolving into a long-duration crew support system for cislunar and Mars exploration

NextSTEP Habitation Systems BAA Overview

- **This BAA on Habitation systems was implemented to identify potential public – private partnerships on habitation systems that can leverage existing or planned commercial systems and activities to perform NASA proving ground objectives**

- The BAA for Habitation systems is for development of concepts and technology investigation for:
  - An initial habitation capability in cislunar space with extensibility for in-space transit habitation or
  - The capabilities that enable a potential use of commercial Low Earth Orbit (LEO) habitation capabilities coupled with government-provided exploration in-space habitation capabilities in cislunar space.
- The studies are to identify habitation capabilities that could be implemented in a modular way that could gradually build up the capabilities required for a deep space transit capability.
- This habitation capability will serve as the first foundational cornerstone of a future deep space transit capability and may include multiple elements over a phased build out as the architecture and a commercial and international partnership strategy is further refined.

NextSTEP Habitation Systems BAA Overview

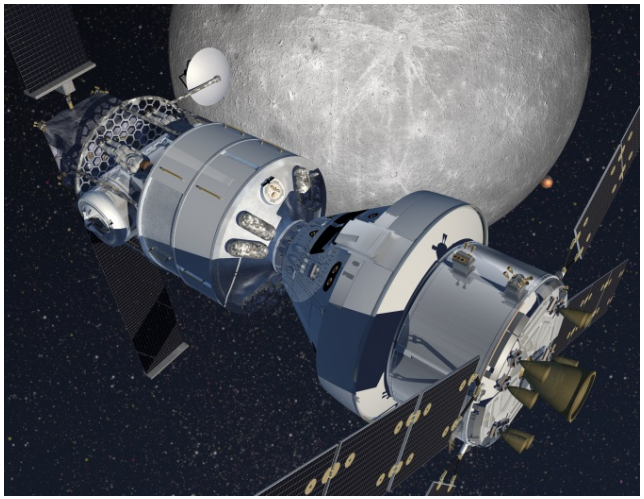
- **Concept is expected to be used to augment planned cislunar missions as well as to provide the function of a proving ground for future systems in support of human exploration in deep space (beyond cislunar space). The type of missions that could be supported by the initial habitation capability include:**
  - Long Duration Exploration Systems Testing
  - Automation, Tele-operations, and Robotics
  - Human Assisted Sample Return
  - In Situ Resource Utilization (ISRU) Demonstration Missions
  - Human Research in Deep Space
  - Logistics Support
  - General Science

- **Proposers to provide concept studies, technology investigation and concepts of operations to help define the architecture or subsystems of an initial habitat design or the capabilities to enable extended habitation in a modular way that would gradually build up the capabilities for a deep space transit capability that will address areas of mutual interest by leveraging available capabilities.**
- **Depending on the results from the initial studies, NASA may decide to award follow-on contract options for further development of a ground test article and physical mock-up and the manufacturing of the proposed subsystem or protoflight habitat. A proposed statement-of-work for the further development option shall be developed during the initial study phase.**

Lockheed Martin Habitation Systems

Objectives & Technical Approach:

- Apply experience in building NASA's only crewed exploration vehicle, legacy with interplanetary spacecraft, and investment in studying exploration mission concepts (including "Stepping Stones" and habitats) to provide NASA with a heritage solution for an EAM, with high TRL, in a constrained funding environment.
- Leverage Orion subsystems to simplify initial habitat design and reduce cost
- Include MPLM, Columbus, and ATV ICC experience base in LM design of pressurized vessel
- NASA funding will be used to address design maturation of various EAM subsystems and provide a roadmap for using the EAM to address radiation life sciences and ECLSS evolvability
- IRAD-funded studies will address various EAM architectural elements in parallel



Point-of-Departure EAM Concept

Team:

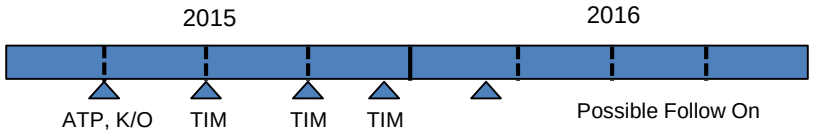
Lockheed Martin (LM):

- Responsible for entire EAM concept
- Will lead design analysis cycle and trade studies
- LM will provide systems engineering and integration
- Will use IRAD to study EAM architecture topics

Thales Alenia Space – Italia (TASI):

- Habitat module based on MPLM, Columbus, and ATV ICC pressurized cargo modules

Schedule:



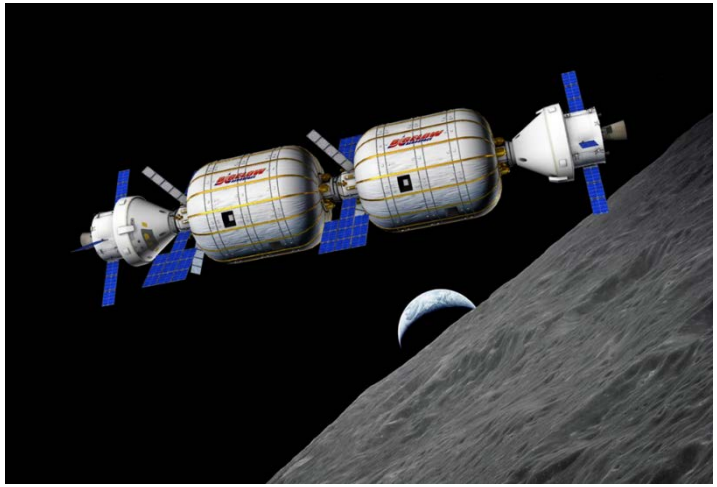
Points of Contact:

- Contracts: Caitlin Foster
  303-971-5207
  Caitlin.e.Foster@lmco.com
- Program Manager: William Pratt
  303-971-3091
  William.d.pratt@lmco.com

B330 EHM Project Proposal

General Approach:

Bigelow Aerospace will produce a conceptual study illustrating how its B330 habitats can be used as the EHM to support operations/missions in LEO, DRO, and beyond cislunar space. This material will be developed by Bigelow Aerospace in collaboration with NASA via a series of Technical Interchange and Concept Review meetings taking place at NASA and Bigelow facilities. During this process, Bigelow Aerospace will leverage its 15 years of experience developing next generation habitats including the successful deployment and operation of two pathfinder spacecraft, Genesis I and Genesis II, which were launched in 2006 and 2007 respectively, and the upcoming launch and attachment of the Bigelow Expandable Activity Module ("BEAM") to the International Space Station later this year.



Two B330s and Orions in Lunar Orbit

Team:

Bigelow Aerospace will leverage its world-class team of business leaders, engineers, and scientists to develop and implement this proposal. The Bigelow Aerospace team will include:

- **Robert Bigelow:** CEO of Bigelow Aerospace and the source of its private capital.
- **George Zamka:** Former NASA astronaut that piloted STS-120 and commanded STS-130. Mr. Zamka also served as Deputy Associate Administrator of the FAA's Office of Commercial Space Transportation.
- **Dr. Colm Kelleher:** Manager/Chief Scientist for Environmental Control and Life Support Systems at Bigelow Aerospace.
- **Derek Hassmann:** Previously served as the ISS Flight Director.
- **Mike Gold:** Director of D.C. Operations & Business Growth for Bigelow Aerospace.

Point of Contact

Mike Gold
Director of D.C. Operations & Business Growth
Tel: (202) 274-0227
E-mail: mgold@bigelowaerospace.com

Orbital NextSTEP Habitation Systems Proposal

Objectives & Technical Approach:

- **EAM Concept Development**
  - Develop an Architecture, Concept Of Operations, and Functional Configuration Baseline (FCB) for evolvable exploration augmentation modules.
  - Identify and perform critical Exploration Augmentation Module (EAM) requirements trades.
  - Identify and prioritize key EAM subsystem elements required to support long-duration missions to destinations in our Solar system.
- **Technology Maturation Planning**
  - Confirm Technical Performance Measures (TPMs).
  - Identify and prioritize critical State-of-the-Art (SOA) technologies to be matured and demonstrated in the next three to five years.
  - Define and cost a Standard Technology Demonstration Interface (STDI) for Cygnus flights to the ISS compatible with defined SOA technologies.

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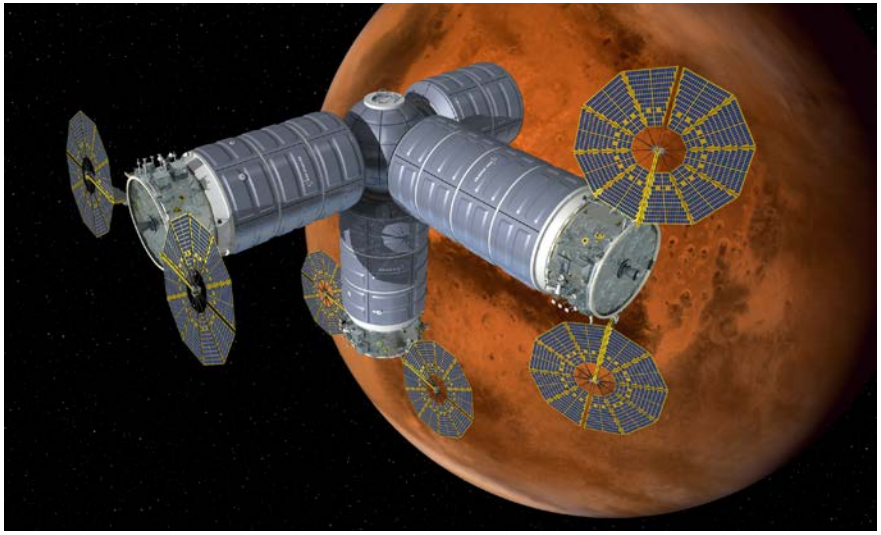


Points Of Contact

Technical Representative:
Marcy Taylor;, Orbital ATK, NextSTEP Project Manager
703-948-8106
marcy.taylor@orbitalatk.com

Contracts Representative
Natalie Imfeld, Orbital ATK, Senior Contracts Manager
(703) 406-5980
Natalie.Imfeld@orbitalatk.com

Schedule

- Phase I Milestones
  1. Kickoff Meeting
  2. Technical Interchange Meeting #1
  3. Technical Interchange Meeting #2/Concept Review
  4. Technical Interchange Meeting #3
  5. Phase I Completion Review

Boeing NextSTEP BAA Habitation Systems

Initial Boeing Concept for Exploration Habitation System

Points of Contact:

- Keith Reiley, Program Management
  keith.a.reiley@boeing.com
- Kevin Foley, Business Development
  kevin.d.foley@boeing.com
- Brenda Hebert, Contracts
  brenda.k.hebert@boeing.com
- Adam Morgan, Communications
  adam.k.morgan@boeing.com

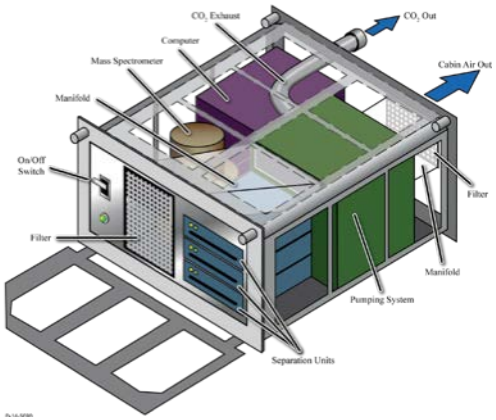
Description:

- Boeing will define an exploration habitation system concept and perform supporting systems studies to validate mission design, vehicle definition, and operational concept
- The approach considers systems that when implemented in a modular way could build up the capabilities required for a long-duration crew support system for cislunar and Mars exploration
- The Boeing habitation system combines the use of commercial capabilities along with government-provided exploration capabilities

NextSTEP BAA Habitation (ECLSS) Awards (3 of 3)

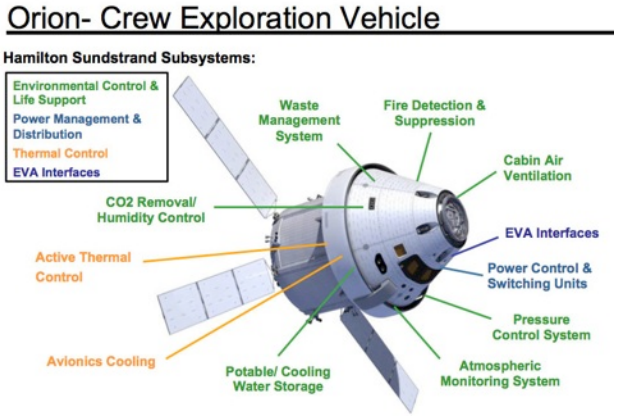
NASA awarded seven habitation projects. Four will address habitat concept development, and three will address Environmental Control and Life Support Systems (ECLSS)

Dynetics, Inc
Huntsville, AL



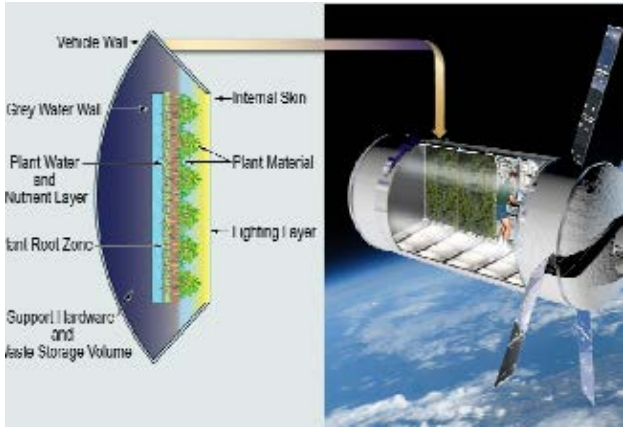
Miniature atmospheric scrubbing system for long-duration exploration and habitation applications. Separates CO2 and other undesirable gases from spacecraft cabin air

Hamilton Sundstrand Space Systems International
Windsor Locks, CT



Larger, more modular ECLSS subsystems, requiring less integration and maximize component commonality

Orbitec
Madison, WI



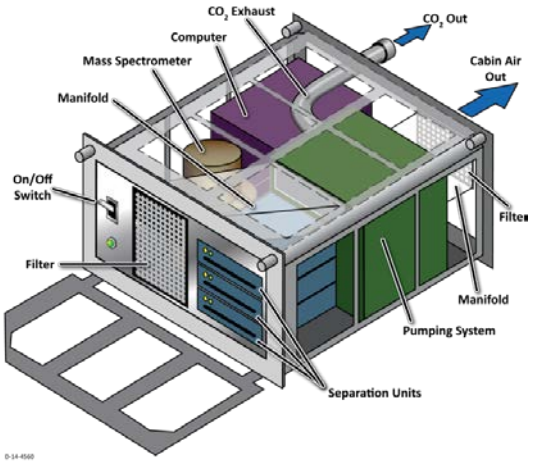
Hybrid Life Support Systems integrating established Physical/Chemical life support with bioproduction systems

Miniature Atmospheric Scrubbing System

Objectives & Technical Approach:

- Develop a miniature CO2 separations system.
- Phase I: focuses on developing and testing a tabletop miniature separations system (MSS-0) that will remove CO2 from air in a laboratory environment. This will baseline system performance, e.g. separation factors, cut, flowrates, and system power requirements.

Concept to be Developed:



Team:

- Ms. K. Doering, Dynetics, Space Division Manager; Project Role: Program Manager (PM).
- Dr. J. Maxwell, Dynetics, Advanced Materials and Nanosystems, Director; Project Role: Principal Investigator (PI).
- Dr. J. Brady, Dynetics, Senior Engineer.
- Mr. K. Borawski, Dynetics, Senior Vac. Technologist.
- Mr. M. Espinoza, Dynetics, Senior Mech. Technician.
- Dynetics, Electromechanical Technician 1, TBD.
- Dynetics, Electromechanical Technician 2, TBD.

Schedule

- Kick-off Meeting/Preliminary Concept Presentation.
- Developing MSS-0 Testbed and Cascade Fabrication Capability, [1st Quarter].
- Initial Fabrication of Cascades and Assembly of MSS-0 Testbed, [2nd Quarter].
- Iterative Testing of Cascades, [3rd Quarter].
- Final Cascade Testing and Selection [4th Quarter].

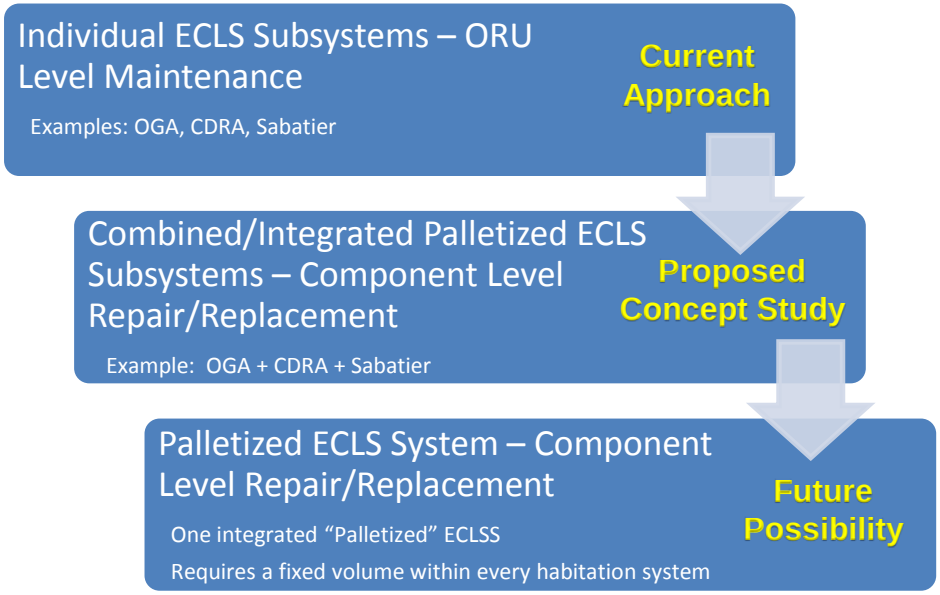
Cost

- Phase I (FY15) Cost: $998k
- Total Cost Sharing by Dynetics: $5.3M

Environmental Control Life Support Systems Modularity Study

Objectives & Technical Approach:

- Create Integrated Module Concepts, Including a full ECLSS and TMS compliment to support needs of a cislunar orbit
- Develop a rules-based analytical study that outlines the impact crew size for different space stations or vehicles against resultant ECLS Modules' weight and volume.
- Develop a set of maintenance design concepts that will allow the crew to repair/replace ECLS components in-orbit.
- Scrub developed EAM ECLSS Schematics to increase common components across subsystems, the intent is to reduce the number of spares required on-orbit.
- Develop System ConOps and outline new Safety Concerns.



Integrated Product Team Members:

- Program – Darren Samplatsky will act as the team lead. He has proven repeated success in efficiently meeting challenging ECLS objectives
- Systems – Mike Heldmann will provide System leadership with expertise in all ECLS Systems, specifically OGA and Water Processor.
- Design – Tom Stapleton will provide innovative Design Leadership, with expertise in System Packaging for the STS, ISS and Orion Space Vehicles.

Major Milestones:

- System ConOps complete, June 2015
- System Schematics complete, Sept. 2015
- Common Component study complete, Sept. 2015
- Palletized subsystem concept models complete, December 2015
- In-flight maintenance concepts complete Dec. 2015
- Crew Impact Study Complete December 2015

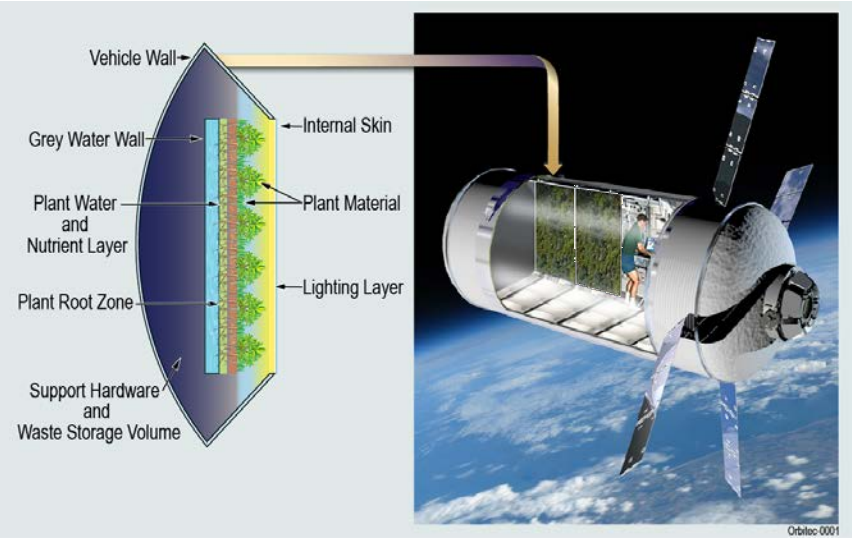
Cost

- Total cost to NASA: $795,456
- Total cost sharing from commercial partner: $849,974

Hybrid Life Support System (HLSS)

Objectives & Technical Approach

- Enhance exploration environmental control and life support through hybrid bioregenerative (BIO) and physical-chemical (PC) systems
- Concept studies for increasing bioregenerative component of HLSS
- Trade studies to determine optimal mix of BIO/PC technologies for different mission phases
- Detailed test plan to advance TRL of HLSS technologies
- Greenwall test as next step in HLSS development



Team

Key team members, ORBITEC

- Dr. Robert Morrow, Project Manager and Bioregenerative Life Support Subject Matter Expert
- Mr. Robert Richter, Subject Matter Expert –Life Support System development and testing
- Mr. Jeff Johnson, Systems Engineer -Life Support System design and analysis
- Mr. Gill Tellez, Engineer –Systems designer
- Mr. Ross Remiker, Engineer – Systems designer

Schedule

•Kickoff meeting	03/2015
•Greenwall CDR	04/2015
•Concept study complete	05/2015
•TIM & Status meeting	06/2015
•Greenwall prototype complete	08/2015
•TIM & Concept review	09/2015
•LSS architectures review	10/2015
•TIM & Status meeting	11/2015
•Tech Development plan	01/2016
•Final briefing	02/2016

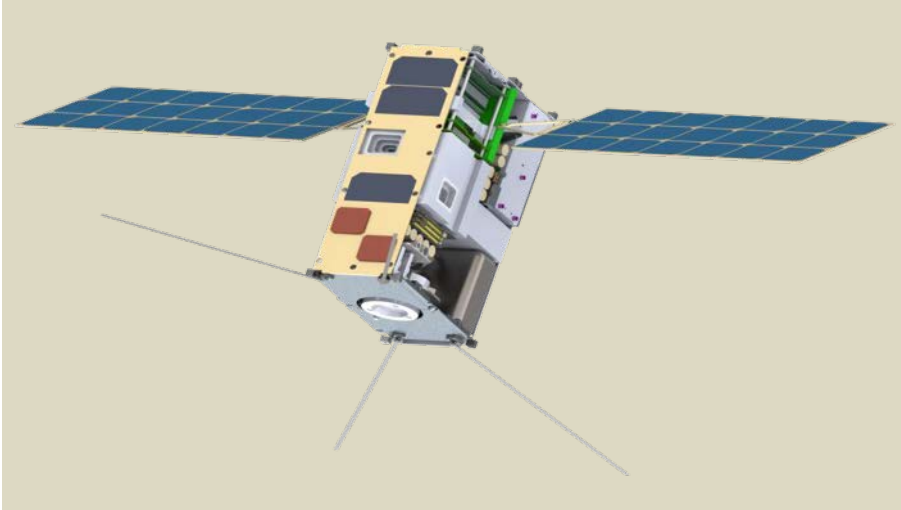
Cost

- Total cost to NASA: $600,000
- Total cost sharing from ORBITEC: $1.2M (2:1)

NextSTEP: Two BAA Small Satellite Awards

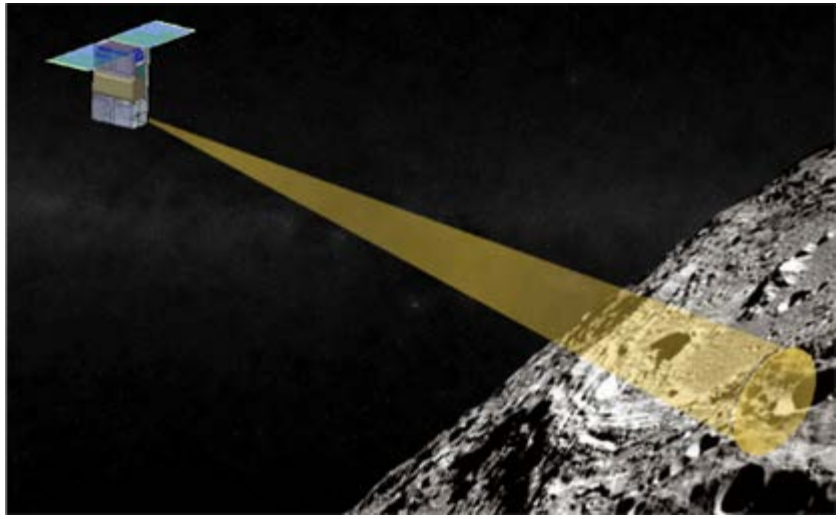
Two CubeSat projects will address Strategic Knowledge Gaps

Morehead State University
Morehead, KY



6U Lunar IceCube
Prospect for water in ice, liquid, and vapor forms and other lunar volatiles from a low-perigee, highly inclined lunar orbit using a compact IR spectrometer

Lockheed Martin
Denver, CO



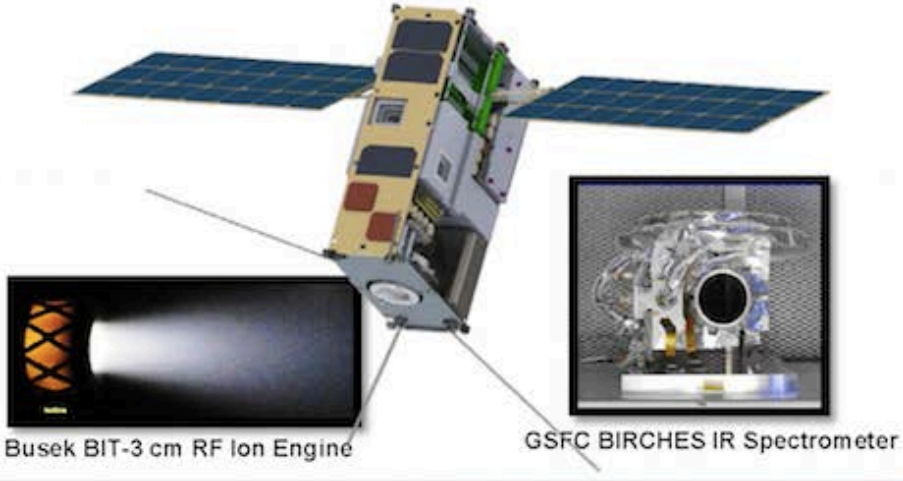
Skyfire 6U CubeSat
GEO Technology Demo
Will perform lunar flyby, collecting spectroscopy and thermography address both Moon and Mars SKGs for surface characterization, remote sensing, and site selection.

Lunar IceCube

Objectives & Technical Approach:

- A 6U CubeSat mission to prospect for water in ice, liquid, and vapor forms and other lunar volatiles from a low-perigee, inclined lunar orbit using a compact IR spectrometer. Lunar IceCube 6U will:
  - be deployed during lunar trajectory by the SLS on EM-1
  - use an innovative RF Ion engine to achieve lunar capture and a science orbit of 100 km perilune
  - fully characterize water and other volatiles with high spectral resolution (5 nm) and wavelength range (1 to 4 μm)

Lunar IceCube in Flight Configuration



Team: *University, Aerospace Industry, Government*

- **Morehead State University Space Science Center**
  Ben Malphrus (PI), Bob Twiggs, Jeff Kruth, Kevin Brown, Roger McNeil, intrepid graduate and undergraduate STEM students
- **The Busek Company**
  Kurth Hohman, Vlad Hruby, Mike Tsay
- **NASA Goddard Spaceflight Center**
  Science Team: Pamela Clark, Dennis Reuter, Robert MacDowall, Clifford Brambora, Deepak Patel, Ian Banks
  Navigation and Tracking: David Folta
- **NASA Goddard Spaceflight Center and Catholic University of America**
  Pamela Clark (Science PI)

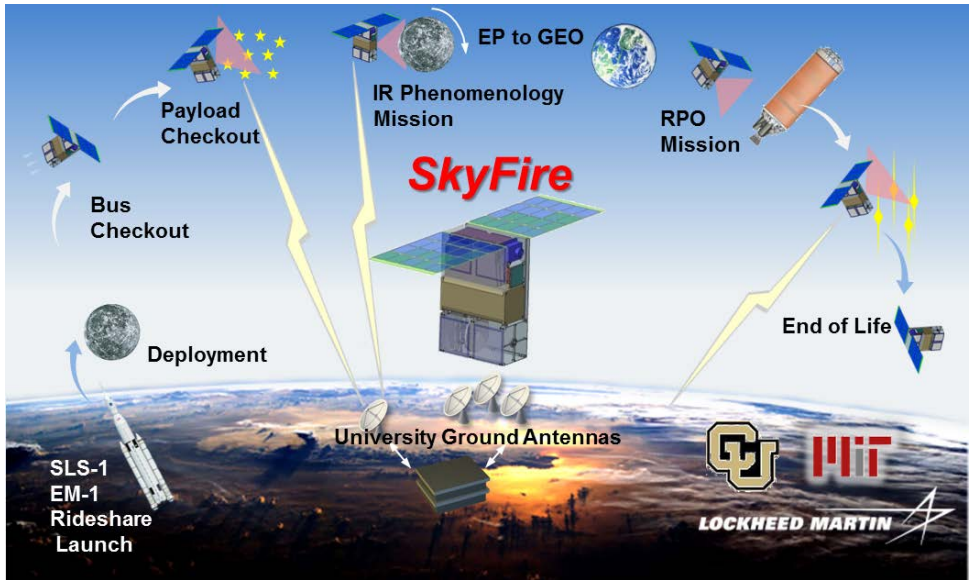
Schedule:

- Initiate Program: Q1 2015
- TIMs, Reviews, Milestones
  As per Requirement
- Launch/LEOP
  SLS Maiden Flight
- Lunar Transit
  Launch +6 Months
- Science Orbit/Mission
  Arrival +3 Months
- Disposal: Q1 2020

Small Satellite Missions: Lockheed Martin SkyFire

Objectives & Technical Approach:

- Lockheed Martin is building the SkyFire cubesat as a technology development platform that will be co-manifested with additional cubesats on the SLS-1 EM-1 test flight
- Following separation from SLS, SkyFire will fly by the moon taking infrared sensor data in order to enhance our knowledge of the lunar surface
- Using electrospray propulsion, the spacecraft orbit will be lowered to the GEO 'graveyard' orbit for more science and technology mission objectives
- SkyFire will leverage Lockheed Martin's successful additive manufacturing experience for deep space missions



Teammates:

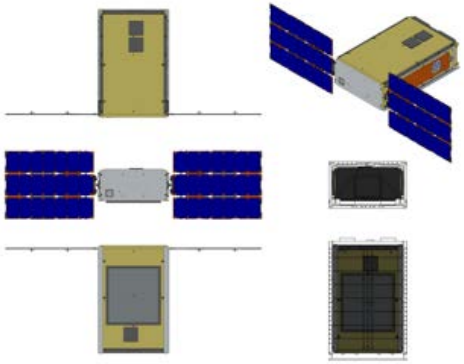
- The Lockheed Martin spacecraft team will consist of the 'Digital Generation' of young spacecraft engineers working with members of the university community
- With SkyFire, LM achieves the multiple benefits of workforce and technology development in partnership with NASA
- Key technology team members:
  - Massachusetts Institute of Technology (MIT)/Accion
  - University of Colorado

Lockheed Martin Contacts:

Program Manager – John Ringelberg
John.c.Ringelberg@lmco.com
Contracts POC - Caitlin Foster
Caitlin.e.Foster@lmco.com

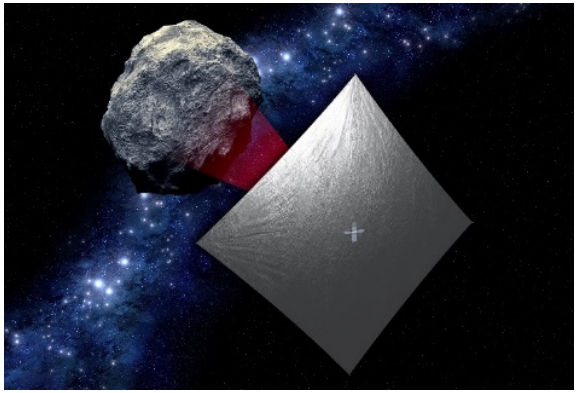
CubeSat Propulsion Capabilities

Deployable & Gimbaled Solar Arrays



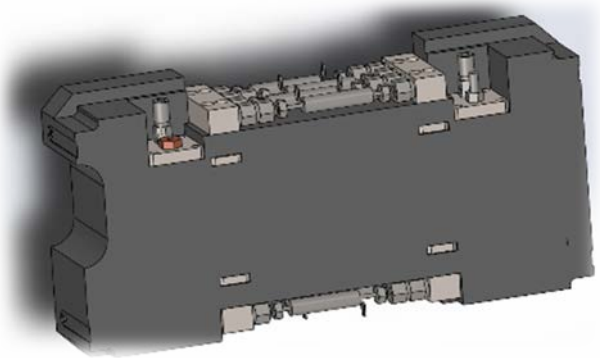
Gimbal solar arrays provide operational flexibility by allowing body-mounted antennae to be pointed at Earth while Panels are angled toward the sun. This reduces system complexity compared to typical body-mounted solar sails

Solar Sail Propulsion



The development of solar and drag sail propulsion will demonstrate large (85 m^2) sail folding and deployment; thermal and structural analysis of thin films and fabrication of large booms (7m length)

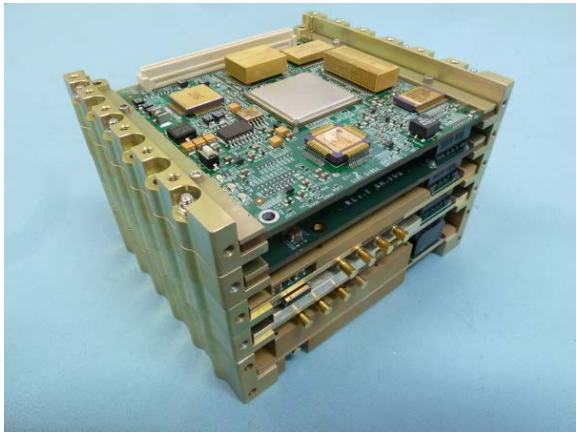
Cold Gas Propulsion



First demonstration of Cold gas systems that make use of a non-toxic propellant to support deep space attitude & momentum management control operations. Low-Earth Orbit Cubesats use magnetic torquers for detumble or momentum management

CubeSat Communications Capabilities

Iris (v2) transponder

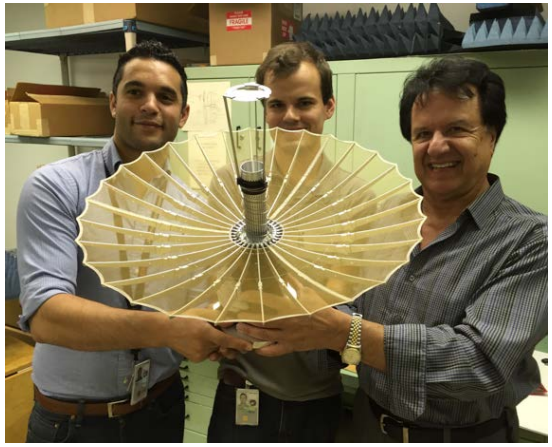


Based on a software defined radio, this device uses the latest technology to provide low cost two-way x-band communications, two-way ranging and navigational aids for deep space Cubesats

Medium Gain Antennae

Antenna technology adapted to the correct form factor optimized for deep space Cubesats. The Medium Gain Antannae provide a reasonable data rate (1Kbps ove 1AU) for doing focused science and technology investigations

High Gain Antennae



This deployable Ka-band antenna supports higher data rates for deep space Cubesats. It requires about 1.5 U of volume and deploys to create a 0.5m parabolic dish

Flight Computing and ADCS Capabilities

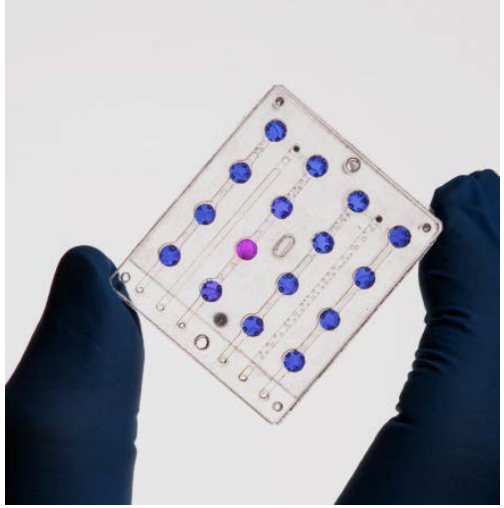
Sphinx Flight Computer

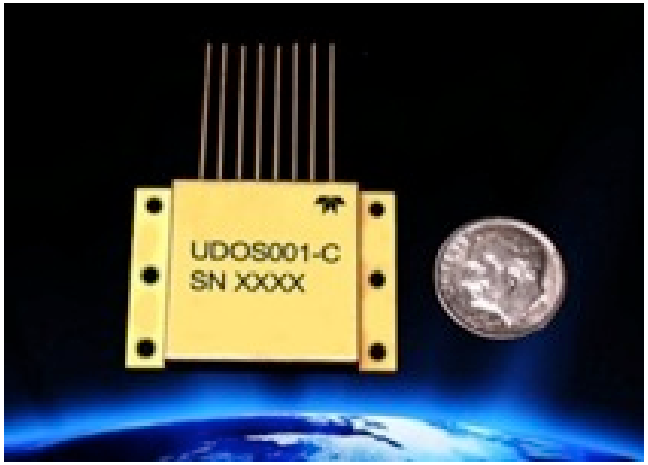
This dual-core rad hard LEON 3 FT based computer uses minimal power, was designed to survive the deep space environment and enable increased autonomy and data processing for deep space Cubesats.

Attitude Determination Control System (ADCS)

The inability to use Earth's magnetic field for attitude control led the development of the ADCS using star tracker, Inertial Measurement Unit (IMU), and sun sensors. Reaction wheels provide attitude control capability while a cold gas thruster system is used to manage the momentum

Biological Testing Capabilities





Integrated Microfluid Advancements

Deep space autonomous microbiological experiments are enabled by the development of a nee microfluidics capability with the following attributes:

- Nine 16-well fluidic cards (144 wells) integrated on a monolithic manifold
- Dormant fluidic cards refrigerated; active cards at growth temperature
- Integrated optical calibration cell per manifold
- Autoclave sterilization
- Maximum anticipated stasis: 18 months (tested to > 12 mos. to date)

Radiation Sensor Advancements

TimePix solid-state device measures linear energy transfer spectra, stores hourly bin totals, download “local space weather” snapshots

Total integrating dosimeter (TID)

- Teledyne µDOS001
- ranged analog outputs (low, med, high, log)
- 15 µrad res. (~20 s ambient GCR)

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