Exploration Technology Strategic Investments

Exploration

Emphasis on the Moon
Keeping an Eye Towards Mars and Beyond

Commerce

Investing in the Growing Space Economy
Early Stage Innovation
- NASA Innovative Advanced Concepts
- Space Tech Research Grants
- Center Innovation Fund/Early Career Initiative

Technology Maturation
- Game Changing Development

Technology Demonstrations
- Technology Demonstration Missions
- Small Spacecraft Technology
- Flight Opportunities

Partnerships & Technology Transfer
- Technology Transfer
- Prizes and Challenges
- iTech

SBIR/STTR
Key Technology Focus Areas

- Advanced environmental control and life support systems and In-Situ Resource Utilization
- Power and propulsion technologies
- Advanced communications, navigation and avionics
- In-space manufacturing and on-orbit assembly
- Advanced materials
- Entry, Descent and Landing
- Autonomous operations
Exploration Technology Investment Strategy

- Fund projects along a broad Technology Readiness Level (TRL) spectrum (1-7)
- Focus on enabling lunar exploration
  - Exploration Federated Team established to facilitate Exploration Campaign integration across the Mission Directorates (senior agency officials-DAA level)
- Implement critical technology demonstrations to enable lunar exploration including Lunar Gateway (e.g., SEP, fuel transfer)
- Utilize commercial lander services and infuse technology for human exploration class landers (e.g., Precision Landing, Cryo Fluid Management)
- Establish a Lunar Surface Innovation Initiative (LSII) to serve as a catalyst for enabling critical technologies required for humans to successfully operate on the lunar surface.
  - Includes fission surface power in situ resource utilization and other key technologies
- Pursue technology demonstration payloads for Commercial Lunar Payload Services, and Gateway
  - Excellent opportunity to utilize NASA personnel (especially early career) and Universities across entire portfolio
- Continue to support technologies readied for flight (e.g., LCRD, DSOC, TRN and MOXIE on Mars 2020, In-Space Manufacturing on ISS)
• Maintain Early Stage investments at ~8% of Exploration Technology budget
  • Ensures a balance of lower TRL concepts sourced from academia and the NASA workforce with industry participation
  • Added emphasis on transitioning key early stage technologies to mid TRL level
• Pursue Public-Private Partnerships across portfolio
• Enhance the Flight Opportunities Program to improve research opportunities on suborbital platforms with emphasis on exploration
• Pursue Small Spacecraft Technologies to develop and demonstrate capabilities for rapid and affordable exploration beyond low Earth orbit and into deep space
  • Provide responsive platforms for scouting lunar terrain, identifying space resources, supporting missions beyond Earth
• Maintain commitment to an integrated Agency-wide SBIR/STTR program that supports both commercial interests and NASA missions with added emphasis on Lunar Exploration Campaign
• Keep an eye towards Mars tall pole critical technology development and continue to support exploration related science goals
**FY 2018 Key Accomplishments**

**Kilopower**
Successful test completed demonstrating a 1-kW surface electrical power system using nuclear fission, which will enable long-duration stays on planetary surfaces with minimal to no solar power resources.

**Small Spacecraft**
Two small spacecraft (Integrated Solar Array and Reflect Antenna and Optical Communication and Sensor Demonstration) missions were successfully launched aboard Orbital ATK’s Cygnus spacecraft.

**In Space Robotic Manufacturing & Assembly**
All 3 contractors completed Phase I (design, build and test/demo) successfully; pursuing flight demo with two concepts.

**Station Explorer for X-ray Timing and Navigation Technology (SEXTANT)**
Aboard ISS demonstrated fully autonomous X-ray navigation in space — a capability that could revolutionize NASA’s ability in the future to pilot robotic spacecraft to the far reaches of the solar system and beyond.

**PUFFER**
Technology demonstration of the Pop-Up Flat Folding Explorer Robot, which will advance NASA’s ability to explore unchartered planetary surfaces.

**Solar Electric Propulsion**
Completed preliminary design review for Advanced Electric Propulsion system.
FY 2018 Key Accomplishments

Laser Communications Relay Demonstration
Successfully completed system build for testing to support a 2020 launch with STPSat-6

Flight Opportunities Testing for Precision Landing Technologies
Successful flight test of a Navigation Doppler Lidar and Lander Vision System for future robotic and crewed missions

Deep Space Optical Communications
Completed System Requirements Review and KDP-B for flight demonstration on the Psyche mission

SBIR/STTR Industry Day
Over 450 innovators from across the country participated in 2nd workshop

Space Technology Research Institutes
Successfully completed Year 1

Restore-L
Completed Preliminary Design Review on November 2017

Centennial Challenges Program
Awarded more than $1.5 million for technology solutions toward the Cube Quest, 3D Printed Habitat and the Space Robotics Challenges.
FY 2019-2020 Plans

**MOXIE**
*March 2019* delivery to Mars 2020 for *July 2020* Launch

**Terrain Relative Navigation**
*December 2018*
Delivery for integration on Mars 2020

**Laser Comm Relay Demo**
*Late 2019*
Payload delivery for bus integration

**Deep Space Optical Comm**
*Spring 2019* KDP-C for the flight terminal

**High Performance Spaceflight Computing (HPSC)**
*FY 2020*
Completion of critical design

**SPLICE**
*October 2019*
Complete NDL environmental testing

**Refabricator**
*Delivery and Installation aboard ISS February 2019*
The first integrated recycler and 3D printer was successfully installed

**Astrobee**
*April 2019*
Will be headed to ISS for demonstration

**Restore-L**
*April 2019*
Spacecraft critical design review
*Late 2019*
Mission CDR

**In Space Robotic Manufacturing and Assembly project**
*In 2019* will transition one or more concepts from ground to flight demonstration

**Flight Opportunities Campaigns**
FY 2019-2020 Plans

**eCryo**  
December 2019  
SHIVER Testing Complete

**Deployable Composite Boom**  
August 2019  
Manufactured boom and deployment system will be demonstrated

**Extreme Environment Solar Power**  
July 2019  
Developing solar cell concentrator technology for low-intensity, low-temperature space power applications. Hardware will be demonstrated for subsequent technology demonstration on SMD’s future mission DART

**Solar Electric Propulsion**  
FY19: Develop and test EDU/ETU/qualification hardware and complete KDP-C  
FY20: Complete Critical Design Review, build qualification units and begin testing.

**DSAC & GPIM NET**  
May 2019  
Launch Aboard STP-2

**LOFTID**  
April 2019  
Prem. Design Review  
July 2020 delivery to launch vehicle

**Nuclear Thermal Propulsion**  
September 2019  
System test of a nuclear fuel element that will reduce the risk and demonstrate feasibility of nuclear thermal propulsion

**RRM3**  
November 2018  
ISS on-orbit operations of methane cryogenic fluids demo in FY19 and FY20

**Space Technology Research Institutes (STRI)**  
June 2019  
Performance test results of two advanced oxygen recovery systems will be available in June 2019 for baseline comparison of capability

**STRI18**  
Selection Announcement expected in late March 2019

**SpaceCraft Oxygen Recovery (SCOR)**  
June 2019  
Performance test results of two advanced oxygen recovery systems will be available in June 2019 for baseline comparison of capability

**Composite Technology for Exploration**  
September 2019  
Complete testing of composite joint technology that will reduce launch dry mass
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*LCRD estimate reflects KDP-C baseline. The project is undergoing a replan due to USAF NGIS spacecraft bus technical and bus problems. Replan is targeted for completion in April 2019.
TECHNOLOGY DRIVES EXPLORATION
SAMPLING OF CURRENT INVESTMENTS

ORION & SLS
- 3D Woven Compression Pads
- Rendezvous and Proximity Operations Sensors
- Heat Exchanger
- Composite Joints
- RAMPT Propulsion Tech

GATEWAY
- Solar Electric Propulsion
- Optical Communications
- In Space Servicing
- In Space Manufacturing
- Smart Autonomous Systems
- Robotic Refueling
- GCR Shielding
- EM-1 CubeSats

MARS
- EDL/LOFTID
- MEDLIZ
- MOXIE
- MEDA
- NTP
- DSOC

LANDER AND SURFACE OPERATIONS
- Precision Landing/Sensors
  - SPLICE
  - Lunar TRN/Doppler Lidar
  - Tipping Point Technologies
  - High Performance Spaceflight Computing
- Cryogenic Fluid Management
  - eCryo
  - High Capacity Cryocooler
  - Lander Cryo Fluid Demo
  - Tipping Point Technologies
- In Situ Resource Utilization
  - Surface Fission Power Demo
  - Bulk Metallic Glass Gears
  - Surface Mobility/PUFFER
  - Deep Space Engine
  - RAMPT Propulsion Tech

Timelines are tentative and will be developed further in FY2019.
Exploration Firsts Through 2024

- CCP (Commercial Crew Program) to ISS
- CLPS (Commercial Lunar Payload Services) for delivering payloads to the Moon
- EM-1 ( Exploration Mission-1) with SLS/Orion Flight
- MARS 2020 Mission (Mars ISRU Test)
- EM-2 ( Exploration Mission-2) Crewed Mission
- GATEWAY: PPE (Platform for Peripheral Experiments)
- Gateway Element
- ENHANCED SCIENCE AND EXPLORATION CAPABILITY Mobility
- GATEWAY: ESPIRIT (Enhanced Science Platform for In-Space Refueling and Transport)
- MODULE WITH TUG (Transporter Utilization and Guidance)
- Deep Space Fueling
- EM-3 ( Exploration Mission-3) Crewed Mission to Gateway
- LUNAR LANDER SYSTEM TEST (Lunar Cryo Fluid Management)

< 2018 Mars InSight Lander

Exploration Technology key contribution
Priority Technologies for Flight Demonstration

- High Performance Spaceflight Computing
- Solar Electric Propulsion
- Precision Landing
- In Situ Resource Utilization
- Lunar Surface Power
- Cryofluid Management
Exploration Technology in Entry, Descent, and Landing

The Safe and Precise Landing Integrated Capabilities Evolution (SPLICE) project; includes high performance spaceflight computing

Mars Entry, Descent, and Landing Instrument (MEDLI 2) on Mars 2020

LeO-based Flight Test Inflatable Decelerator (LOFTID)

Lander Technologies through awards with Astrobotics and Blue Origins
Exploration Technology in Cryogenic Fluid Management

The Robotic Refueling Mission 3 (RRM3) will demonstrate cryogenic fluid transfer and storage technologies.

The Evolvable Cryogenics (eCryo) project.

Flight Demo Gateway & Lunar Precursor CFM Formulation.


Paragon Space Development Corp.: Cryogenic Encapsulating Launch Shroud and Insulated Upper Stage (CELSIUS).

Cryocooler Development enabling zero boil-off.
Lunar Surface Innovation Initiative

In Situ Resource Utilization
Collection, processing, storing and use of material found or manufactured on other astronomical objects

Sustainable Power
Enable continuous power throughout lunar day and night

Extreme Access
Access, navigate, and explore surface/subsurface areas

Extreme Environments
Enable systems to operate through out the full range of lunar surface conditions

Lunar Dust Mitigation
Mitigate lunar dust hazards

Surface Excavation/Construction
Enable affordable, autonomous manufacturing or construction
Exploration Technology for On-orbit Servicing, Assembly, and Manufacturing (OSAM)

Maxar- Dragonfly Robotic System successful ground demonstration for future mission – Archinaut One

Made In Space validated additive manufacturing and robotic assembly with a future mission – Archinaut One

FabLab- Development of a first-generation, in-space, multi-material fabrication laboratory for space missions

Robotics Satellite Servicing - Restore-L approaching CDR

Refabricator is the first integrated 3D printer and recycler in space and currently aboard ISS
Exploration Technology in Deep Space Communications and Navigation

- Testing of the Atomic Clock, GPS Receiver, and Ultra-Stable Oscillator which make up the Deep Space Atomic Clock Payload
  
  Credits: General Atomics Electromagnetic Systems

- Deep Space Optical Communications project hardware being tested.

- Laser Communications Relay Demonstration (LCRD) Project team integrating and testing flight hardware

- Station Explorer for X-ray Timing and Navigation Technology (SEXTANT)

- The Integrated Solar Array and Reflectarray Antenna (ISARA) mission

- Optical Communications and Sensor Demonstration (OCSD) spacecraft

- CubeSat Laser Intersatellite CrosslinK (CLICK) project
Exploration Technology in Advanced Materials

The Rapid Analysis and Manufacturing Propulsion Technology (RAMPT)


Centennial Challenges Program 3D Printed Habitat

Deployable Composite Boom (DCB)

Bulk Metallic Glass Gears (BMG)

Improvement of manufacturing high-strength Carbon Nanotube Technology: >2x strength and lower costs

Improvement of manufacturing high-strength Carbon Nanotube Technology: >2x strength and lower costs
Exploration Technology in Autonomous Systems

- Astrobe- A self-flying robot
- Autonomous Medical Operations (AMO)
- Distributed Spacecraft Autonomy (DSA)
- Integrated Systems for Autonomous Adaptive Caretaking (ISAAC)
- PUFFER
- NASA Centennial Challenges Program Space Robotics Challenge Phase III
- Space Technology Research Institutes (STRI): Smart Deep Space Habitats (SmartHabs) for resilient and autonomous operation.
Exploration Technology in Bio Manufacturing

NASA Centennial Challenges Program
Vascular Tissue And CO2 Conversion Challenges

Space Technology Research Institute: The Center for the Utilization of Biological Engineering in Space (CUBES)

Biosensors for Radiation Exposure

In-Space Targeted Nutrient Production

CO2-Based Biomanufacturing

Leaf Analysis:
- % Weight
- % Moles

Control
- Low
- High

Far-Red
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<th>Exploration Technology Milestones at a Glance</th>
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Flight cadence beyond FY2021 dependant on missions in planning

Flight cadence FY2019 and onward depends on REDDI payload selections and NASA/OGA use of flight services

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Human Class ▲

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Sub-Scale or CLPS ▲

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Small Spacecraft ▲

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Launch ▲ Milestone ▲
Sampling of Industry and OGA Participants in Exploration Technology
STMD By The Numbers (FY 2018)

- Proposals Evaluated: >3,500
- University Partnerships with >120 Universities: >350
- Projects Leading to Flight Demonstrations: >60
- Active Technology Projects: >1,000
- Software Releases: >2,900
- Industry Collaborators: >400
- Transitions since 2011: >900
EXPLORE SPACE TECH
TECHNOLOGY DRIVES EXPLORATION