National Aeronautics and Space Administration

NASA

EXPLORE SPACE TECH

STMD FY 2021 NAC TI&E Briefing

Mr. James Reuter, Associate Administrator for NASA STMD | March 19, 2020

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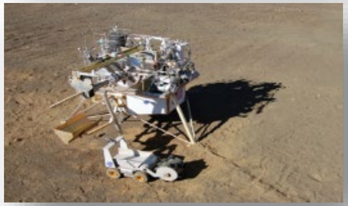
STMD Mission and Guiding Principles



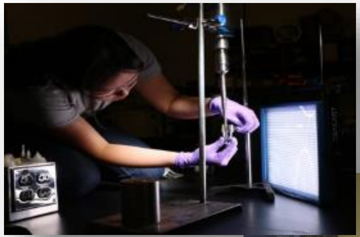
Space Technology develops critical technologies to enable:

- A sustainable Lunar surface presence,
- The future goal of sending humans to Mars, and
- Critical technologies to enable future science and commercial missions.

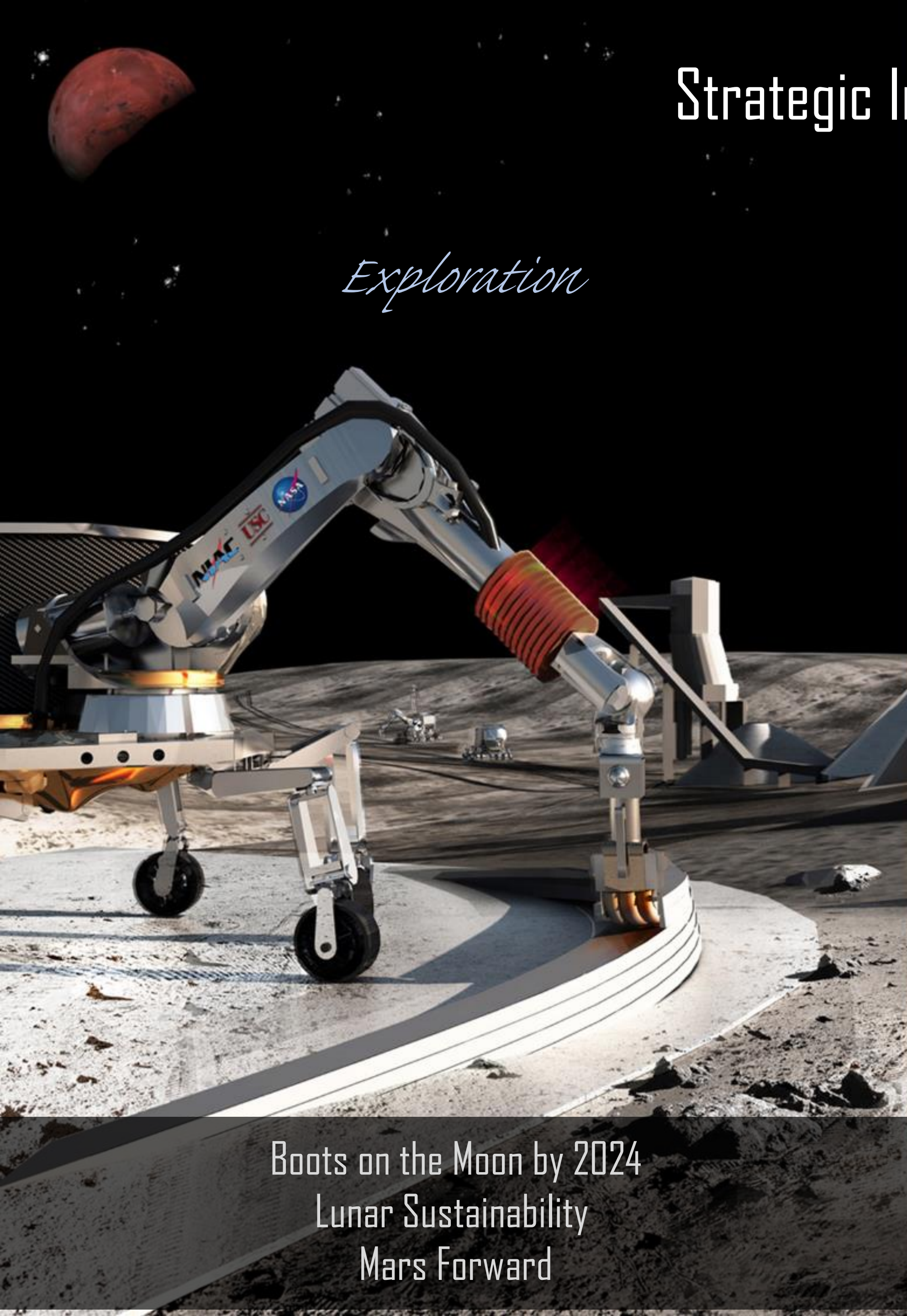
We accomplish this mission by:

- Funding critical technology gaps
- Keeping NASA's space technology pipeline growing with emerging, innovative technologies that promise to drive the future of exploration, science and commercialization.

- ✓ Spark Innovation
- ✓ Engage The Brightest Minds
- ✓ Enable Exploration and Discovery
- ✓ Embrace Competition and Public-Private Partnerships
- ✓ Invest in America

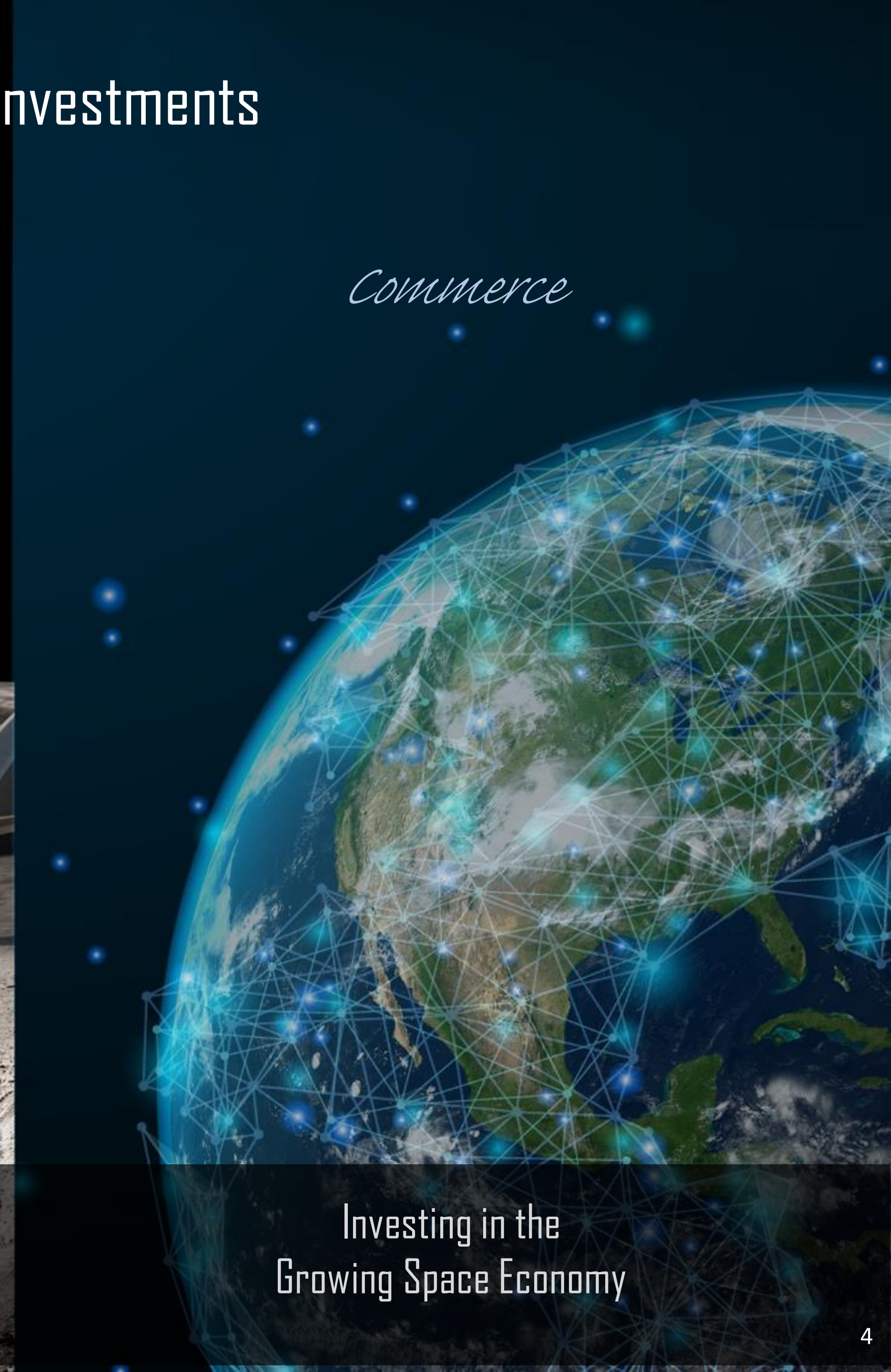


Strategic Investments



Exploration

Boots on the Moon by 2024
Lunar Sustainability
Mars Forward



Commerce

Investing in the
Growing Space Economy

TECHNOLOGY PIPELINE

Early Stage Innovation

- NASA Innovative Advanced Concepts
- Space Tech Research Grants
- Center Innovation Fund/Early Career Initiative

SBIR/STTR

Partnerships & Technology Transfer

- Technology Transfer
- Prizes and Challenges
- iTech

Technology Maturation

- Game Changing Development

Technology Demonstrations

- Technology Demonstration Missions
- Small Spacecraft Technology
- Flight Opportunities

STMD Strategic Framework

LEAD

Ensuring American global leadership in Space Technology

- **Lunar Exploration building to Mars and new discoveries at extreme locations**
- **Robust national space technology engine to meet national needs**
- **U.S. economic growth for space industry**
- **Expanded commercial enterprise in space**

THRUSTS	OUTCOMES	CAPABILITIES
Go ***Rapid, Safe, & Efficient Space Transportation***	• Enable Human Earth-to-Mars Round Trip mission durations less than 750 days. • Enable rapid, low cost delivery of robotic payloads to Moon, Mars and beyond. • Enable reusable, safe launch and in-space propulsion systems that reduce launch and operational costs/complexity and leverage potential destination based ISRU for propellants.	• Cryogenic Fluid Management & Propulsion • Advanced Propulsion
Land ***Expanded Access to Diverse Surface Destinations***	• Enable Lunar and Mars Global Access with ~20t payloads to support human missions. • Land Payloads within 50 meters accuracy while also avoiding local landing hazards.	• Human & Robotic Entry, Descent and Landing • Precision Landing
Live ***Sustainable Living and Working Farther from Earth***	• Conduct Human/Robotic Lunar Surface Missions in excess of 28 days without resupply. • Conduct Human Mars Missions in excess of 800 days including transit without resupply. • Provide greater than 75% of propellant and water/air consumables from local resources for Lunar and Mars missions. • Enable Surface habitats that utilize local construction resources. • Enable Intelligent robotic systems augmenting operations during crewed and un-crewed mission segments.	• Sustained human life support systems • Operate in Extreme Environments • Advanced Materials, Structures and Manufacturing • Sustainable Power • In-situ Propellant and Consumable Production • Intelligent/Resilient Systems & Advanced Robotics
Explore ***Transformative Missions and Discoveries***	• Enable new discoveries at the Moon, Mars and other extreme locations. • Enable new architectures that are more rapid, affordable, or capable than previously achievable. • Enable new approaches for in-space servicing, assembly and manufacturing. • Enable next generation space data processing with higher performance computing, communications and navigation in harsh deep space environments.	• Extreme Access • On-orbit Servicing, Assembly and Manufacturing • Small Spacecraft Technologies • Advanced Avionics • Advanced Communications & Navigation

Note: Multiple Capabilities are cross cutting and support multiple Thrusts. Primary emphasis is shown

STMD Investment Strategy

- **Deliver Technologies to enable a sustainable Moon to Mars presence**
  - Qualify high power solar electric propulsion system for flight on Gateway Power and Propulsion Element
  - Demonstrate precision landing and hazard avoidance technologies with Commercial Lunar Payload Services (CLPS) lander partnerships and suborbital launch providers, leading to human lander implementations
  - Develop long term cryogenic storage capability with very low boiloff rates for advanced human lander and in-space transportation systems
  - Spur the creation of novel technologies needed for lunar surface exploration via the Lunar Surface Innovation Initiative
    - In-situ resource utilization including polar ice to water and regolith to oxygen development paths; culminating in a end-to-end pilot planet demonstration
    - Surface power development including regenerative fuel cells and nuclear fission power reactor
    - Multiple technology developments to address dust mitigation, excavation, construction, and extreme access/environments, including surface robotic scouts
  - Augment ongoing advanced navigation and communications technology developments (Laser Communications Relay Demo, small spacecraft comm demos, Deep Space Atomic Clock) with Moon to Mars demos (e.g.,CAPSTONE/NRHO Pathfinder)
  - Continue use of ISS to demonstrate technologies that apply to Moon to Mars plans (e.g., In-Space Manufacturing, Autonomous Human Assist (Astrobee))

STMD Investment Strategy

- **Utilize entire STMD portfolio and partnerships to enable Moon to Mars while enhancing space commerce**
  - Continue to forge direct partnerships with companies competing to provide Moon to Mars capabilities
    - 11 NextSTEP BAA awards for Appendix E lander refueling and other technologies; In Situ Resource Utilization (ISRU) NextSTEP BAA
    - 19 Announcement of Collaborative Opportunities (ACO) non-reimbursable space act agreement awards in late July 2019; moving to annual awards; 14 Tipping Point selections in September 2019
  - Apply particular emphasis to Lunar Surface Innovation Initiative (LSII)
    - Utilize UARC as system integrator and form a Lunar Surface Consortium composed of industry, academia, and NASA expertise (pilot task started)
    - Support with broader STMD portfolio (e.g., Early Career Initiative, NIAC Phase III, Centennial Challenges, crowdsourcing)
  - Enhance Early Stage Innovation investments (Early Career Initiative, Space Technology Research Grants) to enable and mature technologies for Moon to Mars
    - Maintaining Early Stage Innovation investments at 7-8% of total STMD budget
    - 7 ECI awards in July 2019; most with direct infusion into LSII – increasing awards
    - Adding STRG Lunar Surface Innovation Initiative Research Opportunity

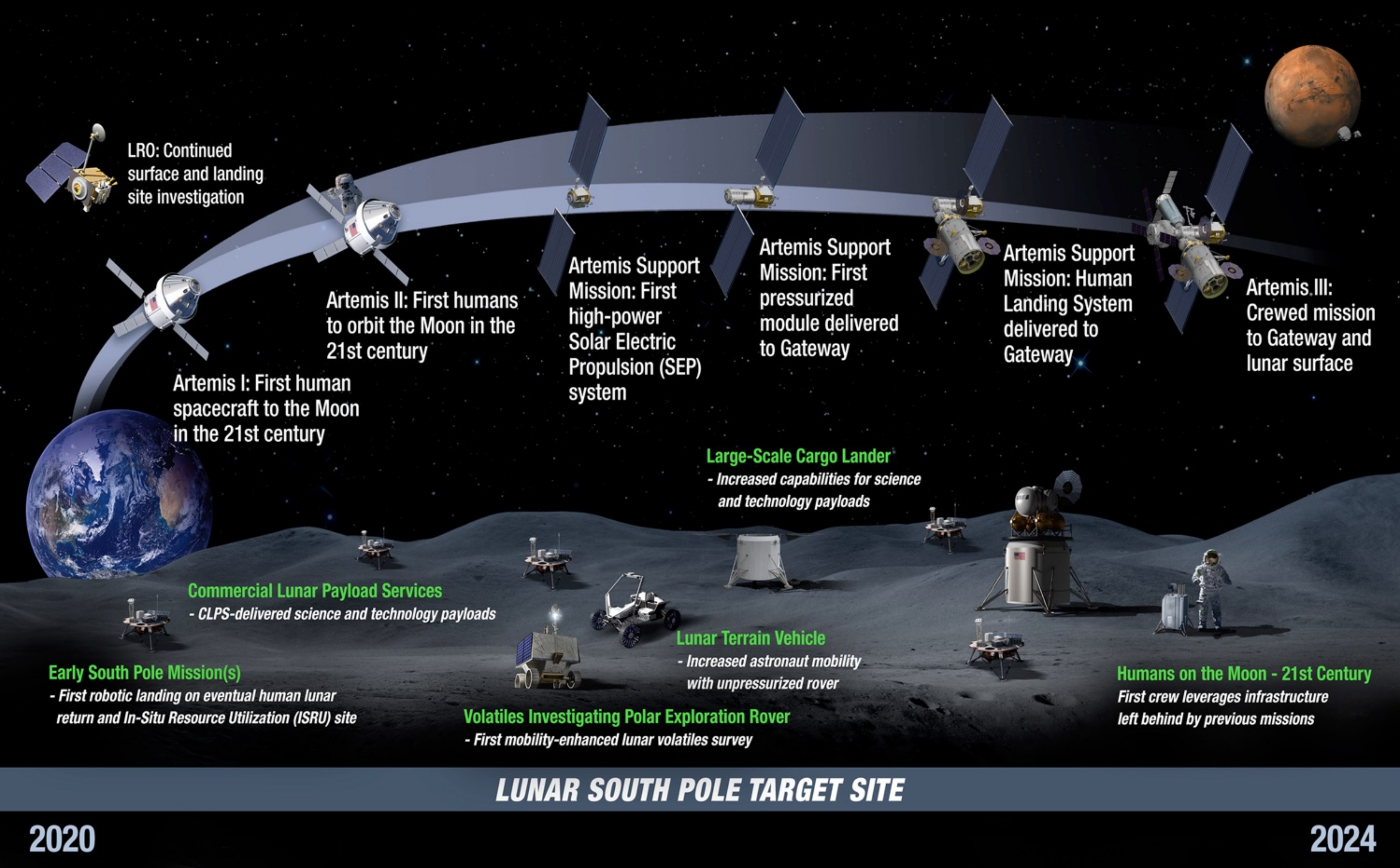
STMD Investment Strategy

- **Utilize entire STMD portfolio and partnerships to enable Moon to Mars while enhancing space commerce (cont.)**
  - Pursue technology payload demonstrations on Commercial Lunar Payload Services and Gateway
  - In final negotiations with the SBA for a policy waiver to increase Phase II Sequential awards to $5M each. Two legislative proposals to increase CCRPP awards to $10M and allow direct Phase II authority have been submitted for consideration in the reauthorization process
  - Improve testing opportunities on suborbital platforms with enhanced Flight Opportunities investments (implemented in FY 2019) – particular emphasis on lunar exploration and space commerce
    - Tech Flights 2020 draft solicitation allows human tended payloads and adds dedicated funding for educational opportunities
  - Continue flight demonstrations for transformative on-orbit assembly and manufacturing technologies (Made In Space Archinaut; Maxar SPIDER)
    - OSAM-1 supports Maxar SPIDER flight mission
    - Restore Mission proposed to be stopped following mission CDR (Sept. 2020) to accommodate funding priorities
    - Qualify critical servicing technologies and transfer to U.S. industry
  - Pursue inter-agency partnerships where they support STMD priorities and multi-agency needs (e.g., Space Nuclear Technologies)

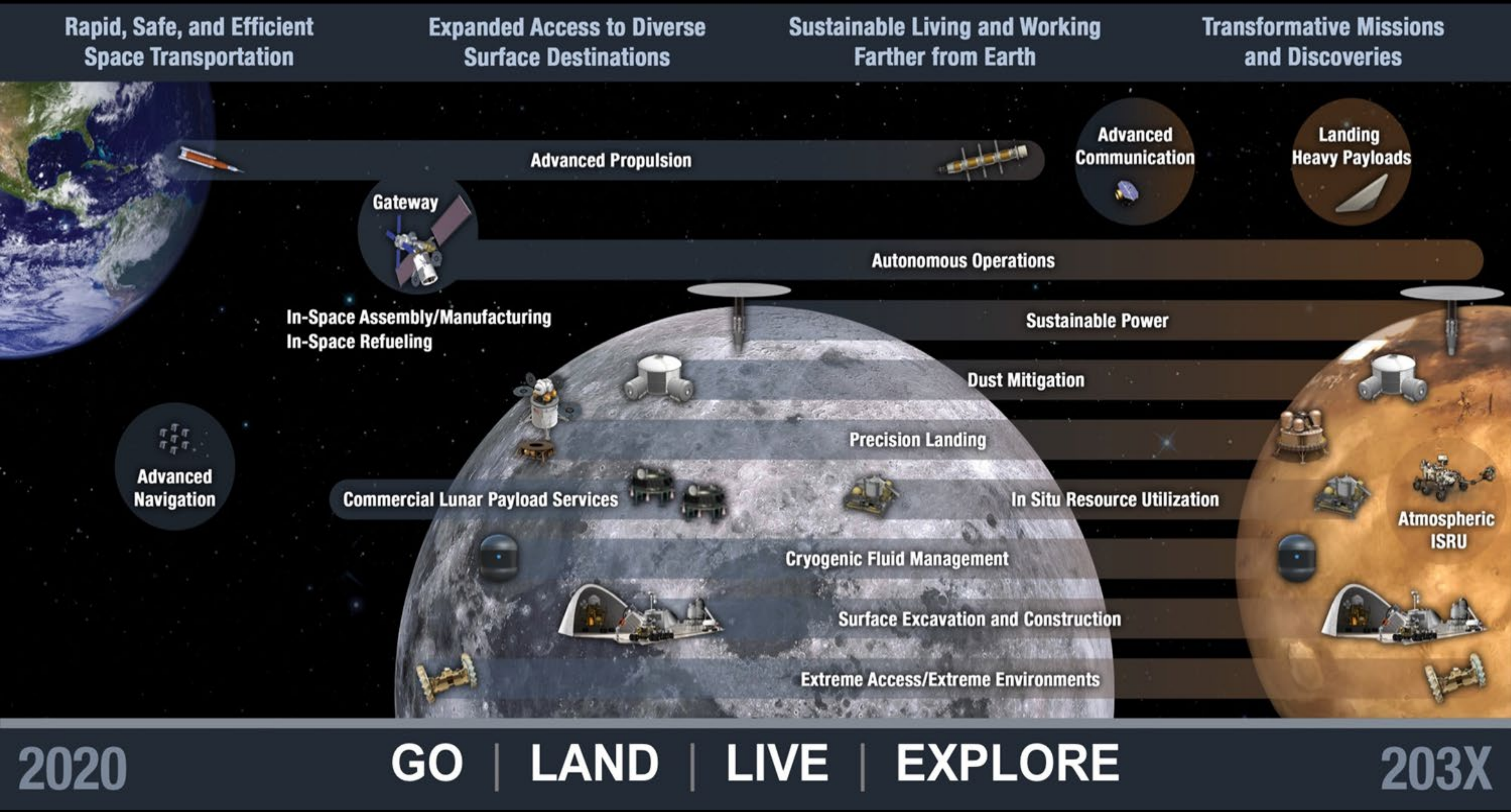
STMD Investment Strategy

- **Invest in unique Mars Forward technologies to ensure readiness for landing humans on Mars**
  - Support investments in Mars related technologies (LOFTID inflatable hypersonic decelerator, Deep Space Atomic Clock, Deep Space Optical Communications, Mars 2020 technologies).
  - Pursue early-stage development of Mars-forward Surface Technologies: Mars atmosphere and surface water ISRU, excavation, dust mitigation, and cross-cutting systems development ultimately resulting in long-duration testing in a simulated Mars environment.
    - Candidate ISRU technology developments will include carbon dioxide collection, carbon dioxide electrolysis and recycling, oxygen liquefaction.
  - Conduct trades and analysis assessments of Mars Entry, Descent, and Landing (EDL) and vehicle systems to inform the Moon-to-Mars Campaign.
  - Pursue a new integrated space nuclear power and propulsion effort to enable robust exploration of Moon and Mars
    - Execute a capability demonstration of a surface power system on the Moon in the 2027 timeframe. Surface power is NASA's most pressing power need.
    - Key fission propulsion technologies need additional development and validation prior to undertaking a flight demonstration with extensibility to Mars transportation
    - Mars Mission analyses are in progress considering both nuclear thermal propulsion and nuclear electric propulsion concepts; the agency has not yet selected a Mars transportation architecture. Includes National Academies study
    - Conducting assessments of the appropriate scope and timing of a nuclear propulsion flight demonstration

Artemis Phase 1: To The Lunar Surface by 2024



Reaching the Moon and Mars Faster With NASA Technology



Exploration Technology FY 2021 Budget Request

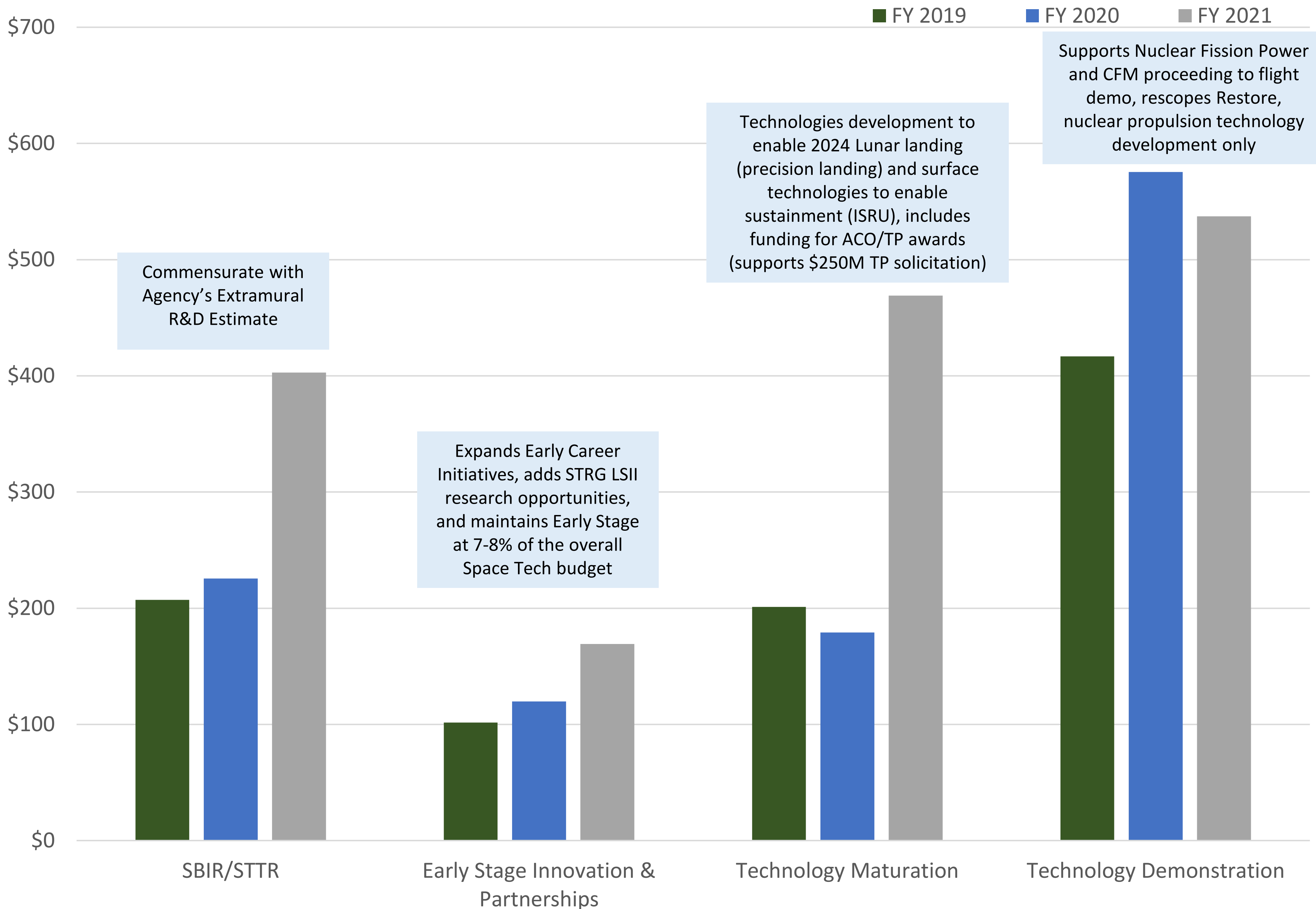
Exploration Technology FY21 Budget Request ($M)	FY 2019	FY 2020 Enacted	FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
SBIR and STTR	**207.2**		**402.8**	**478.7**	**542.6**	**544.8**	**481.1**
Early Stage Innovation and Partnerships	**101.7**		**169.2**	**179.2**	**196.2**	**196.2**	**196.2**
Agency Technology and Innovation	8.8		9.4	9.4	9.4	9.4	9.4
Early Stage Innovation (NIAC, STRG, CIF/ECI)	66.5		123.4	133.4	150.4	150.4	150.4
Partnerships and Technology Transfer (CP&C, Tech Transfer, iTech)	26.4		36.4	36.4	36.4	36.4	36.4
Technology Maturation	**201.2**		**469.1**	**551.5**	**654.1**	**748.4**	**835.8**
Go: Rapid, Safe & Efficient Space Transport	*75.9*		*19.1*	*19.5*	*20.5*	*38.1*	*43.9*
Land: Expanded Access to Diverse Surface Destination	*34.3*		*52.2*	*67.8*	*78.5*	*88.0*	*100.0*
Live: Sustainable Living & Work Far From Earth	*45.7*		*247.3*	*285.0*	*336.4*	*388.7*	*438.2*
Explore: Transformative Missions & Discoveries	*24.6*		*43.6*	*44.8*	*47.1*	*52.1*	*62.7*
Lunar Payload, ACO/TP	*1.9*		*77.4*	*101.1*	*135.0*	*144.0*	*150.0*
Technology Demonstration	**416.8**		**537.2**	**556.0**	**513.4**	**464.8**	**525.1**
OSAM-1 (Satellite Serv & SPIDER)	192.8	227.2	133.5	117.2	59.4	14.6	-
Laser Communications Relay Demonstration	17.2		13.6	-	-	-	-
Solar Electric Propulsion	48.1		48.7	25.4	9.0	5.8	-
Small Spacecraft, Flight Opps & Other Tech Demo	158.7		341.4	413.4	445.0	444.5	525.1
Flight Opportunities	*20.0*		*20.0*	*20.0*	*20.0*	*20.0*	*20.0*
Small Spacecraft	*25.5*		*46.0*	*46.2*	*48.2*	*52.7*	*57.7*
Deep Space Optical Communications	*39.4*		*10.5*	*4.6*	*1.1*	*0.1*	*-*
Archinaut (OSAM-2)	*14.7*		*20.5*	*13.6*	*3.6*	*-*	*-*
Low-Earth Orbit Flight Test Inflatable Decelerator	*20.0*		*20.1*	*10.6*	*-*	*-*	*-*
Cryogenic Fluid Management	*13.8*		*104.2*	*137.0*	*160.1*	*137.3*	*145.5*
Space Nuclear Technologies (includes Nuclear Fission Power and Nuclear Propulsion)	*-*	*110.0*	*100.0*	*142.4*	*168.1*	*190.0*	*256.8*
Total Exploration Technology	**926.9**	**1,100.0**	**1,578.3**	**1,765.4**	**1,906.2**	**1,954.2**	**2,038.2**

STMD Commerce/Crosscutting/Agency and Moon to Mars Budget

Moon to Mars	FY 2019	FY 2020 Enacted	FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
SBIR and STTR	**100.0**		**302.8**	**378.7**	**442.6**	**444.8**	**381.1**
Early Stage Innovation and Partnerships	**52.8**		**113.4**	**124.4**	**141.3**	**141.3**	**141.2**
Agency Technology and Innovation	4.4		4.9	4.9	4.9	4.9	4.9
Early Stage Innovation	41.2		94.7	105.7	122.7	122.7	122.7
Partnerships and Technology Transfer	7.2		13.8	13.8	13.7	13.7	13.6
Technology Maturation	**197.6**		**467.0**	**549.3**	**651.9**	**746.3**	**833.6**
Lunar Payload, ACO/TP, Program Int & Support	23.0		104.8	132.2	169.4	179.3	188.9
Rapid, Safe, & Efficient Space Transportation	75.2		19.1	19.5	20.5	38.1	43.9
Expanded Access to Diverse Surface Destinations	34.3		52.2	67.8	78.5	88.0	100.0
Sustainable Living and Working Farther from Earth	41.9		247.3	285.0	336.4	388.7	438.2
Transformative Missions and Discoveries	23.3		43.6	44.8	47.1	52.1	62.7
Technology Demonstration	**113.5**		**327.9**	**389.6**	**421.7**	**423.1**	**498.0**
Solar Electric Propulsion (SEP)	48.1		48.7	25.4	9.0	5.8	-
Small Spacecraft & Other Tech Demo	65.4		279.2	364.2	412.7	417.3	498.0
Small Spacecraft	*15.9*		*34.9*	*35.0*	*40.6*	*45.6*	*50.6*
Cryogenic Fluid Management (CFM)	*13.8*		*104.2*	*137.0*	*160.1*	*137.3*	*145.5*
LEO Flight Test of an Inflatable Dec (LOFTID)	*20*		*20.1*	*10.6*	*-*	*-*	*-*
Space Nuclear Technologies	*-*	*110.0*	*100.0*	*142.4*	*168.1*	*190.0*	*256.8*
Total	**463.9**	**603.5**	**1,211.1**	**1,442.0**	**1,657.5**	**1,755.5**	**1,854.0**

Commerce/Crosscutting/Agency Support	FY 2019	FY 2020 Enacted	FY 2021	FY 2022	FY 2023	FY 2024	FY 2025
SBIR and STTR	**107.2**		**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Early Stage Innovation and Partnerships	**48.9**		**55.8**	**54.8**	**54.9**	**54.9**	**55.0**
Agency Technology and Innovation	4.4		4.5	4.5	4.5	4.5	4.5
Early Stage Innovation	25.3		28.7	27.7	27.7	27.7	27.7
Partnerships and Technology Transfer	19.2		22.6	22.6	22.7	22.7	22.8
Technology Maturation	**3.6**		**2.1**	**2.2**	**2.2**	**2.1**	**2.2**
Technology Demonstration	**303.3**		**209.3**	**166.4**	**91.7**	**41.7**	**27.1**
OSAM-1 (Satellite Servicing & SPIDER)	192.8	227.2	133.5	117.2	59.4	14.6	0.0
Laser Comm Relay Demo (LCRD)	17.2		13.6	-	-	-	-
Small Spacecraft & Other Tech Demo	93.3		62.2	49.2	32.3	27.2	27.1
Small Spacecraft	*9.6*		*11.1*	*11.2*	*7.6*	*7.1*	*7.1*
Flight Opportunities	*20.0*		*20.0*	*20.0*	*20.0*	*20.0*	*20.0*
Deep Space Optical Comm (DSOC)	*39.4*		*10.5*	*4.6*	*1.1*	*0.1*	*0.0*
Archinaut (OSAM-2)	*14.7*		*20.5*	*13.6*	*3.6*	*0.0*	*0.0*
Total	**463.0**	**496.5**	**367.2**	**323.4**	**248.7**	**198.7**	**184.2**

Changes from FY 2019 to FY 2021



FY 2020-2021: Technology Drives Exploration

Blue Origin Demo of Deorbit, Descent and Landing Lasers
June and December 2020
SPLICE DLC and NDL will be integrated and flown on BO New Shepard suborbital rocket

Composite Technology for Exploration
August 2020
Complete testing of composite joint technology that will reduce launch dry mass

MEDLI 2
February 2021
Mars 2020 enters Mars atmosphere

LOFTID
July 2021
Complete Systems Test with Reentry Vehicle Delivery in **December 2021**

SynBio
January 2020
Sample pack returned from ISS for analysis

Nuclear Thermal Propulsion
September 2020
System feasibility assessment review

RAMPT
Sept 2021
Full Scale Multi-material Thrust Chamber Hot-fire Test

Navigation Doppler Lidar
June 2021
Lunar Demonstration via CLPS

SPLICE
September 2020
HDL EDU suborbital flight test

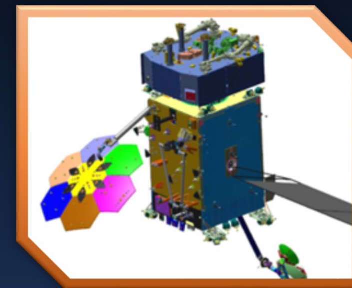
Nuclear Fission Power
Mission Concept Review and Systems Req. Review and Industry Trade Studies **FY 20-21**

Deployable Composite Boom
November 2020
Zero-gravity flight test of DCB technology

FY 2020-2021: Technology Drives Exploration

Lunar Precursor CubeSat Demos
Conduct three Lunar precursor CubeSat Demos including CAPSTONE mission in **FY21**

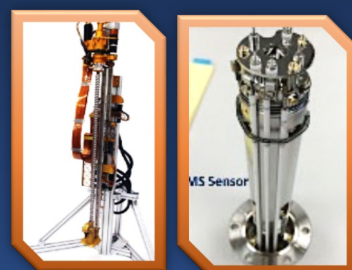
Archinaut (OSAM – 2)
Critical Design Review in **FY21**



OSAM-1
Sept. 2020 Mission Critical Design Review **FY21:** SPIDER Critical Design Review and Integration and Test

Blue Origin Tipping Point- December 2020
BlueNav-L EDL Sensor Suite Demo

Laser Comm Relay Demo
Launch aboard STPSat-6 in **FY21**

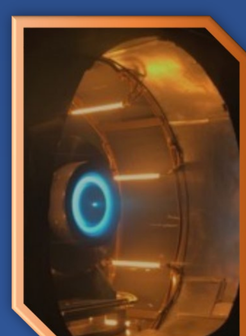


PRIME–Lunar Ice to Water
FY21 Regolith with Ice Characterization demo complete testing and delivery of spaceflight hardware for CLPS Mission

Flight Opportunities Campaigns
FY21 Award of opportunities to industry and academia.

Astrobotics Tipping Point- January 2021
Terrain Relative Navigation Critical Design Review

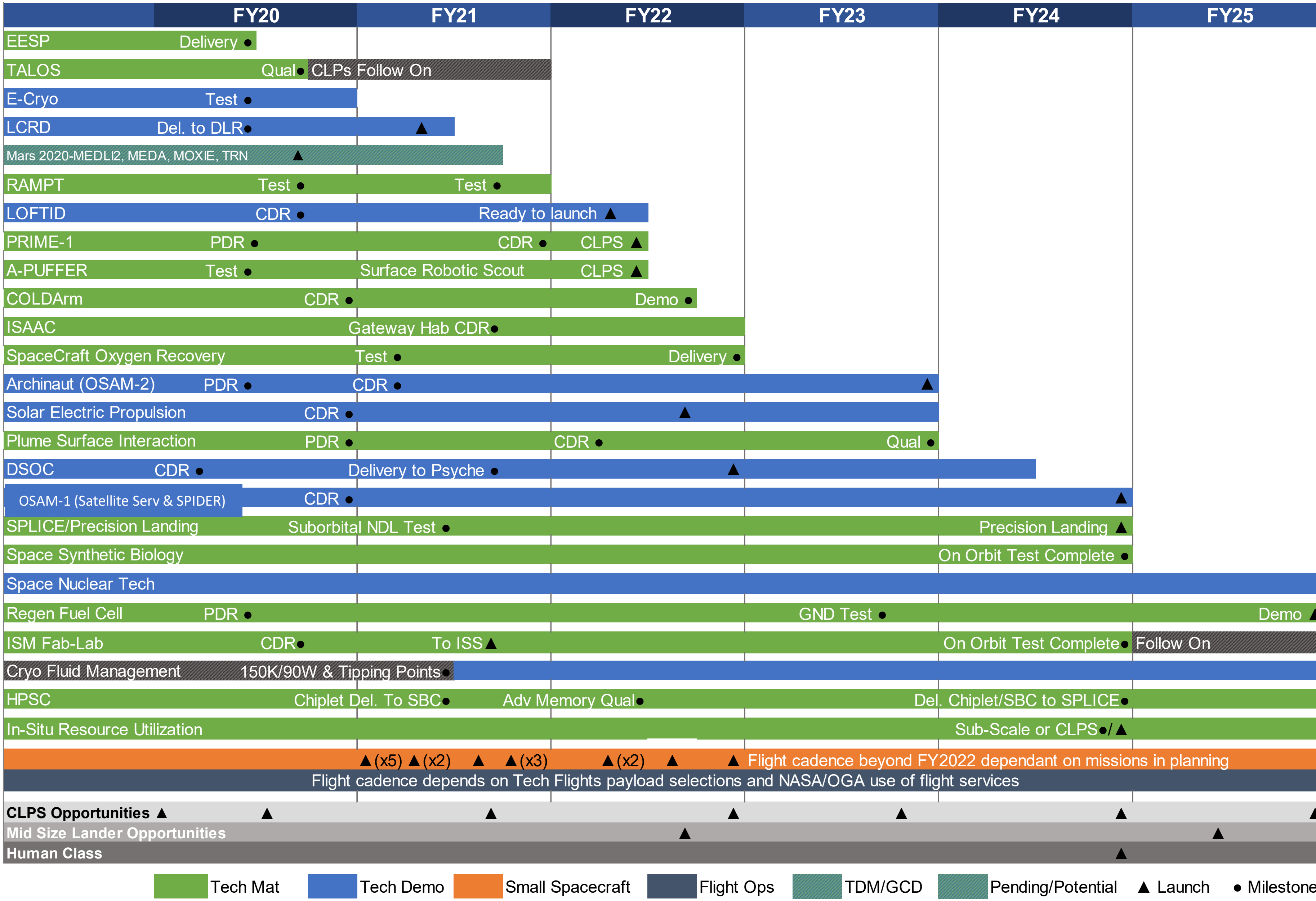
Deep Space Optical Communication
Deliver flight hardware to Psyche for mission



Solar Electric Propulsion
Complete Thruster Qualification String Integration

TALOS
Five thrusters will be used on Astrobotic's first Peregrine Lander **2021**

Exploration Technology Milestones at a Glance



Space Nuclear Power

Nuclear power systems can enable robust exploration of Moon and Mars

- Fission systems can provide abundant and continuous surface power in all environmental conditions on Moon (14.5 d lunar night, permanently shadowed regions) and Mars (dust storms)
- Recent analyses indicate that a Mars fission surface power system is likely to be 2-3x less massive and significantly more reliable than a comparable solar power system
- A fission system designed for a capability demonstration on Moon will be directly applicable to human Mars exploration

Space Nuclear Propulsion

Nuclear propulsion systems can enable robust exploration of Mars

- **There are two basic practical Mars mission trajectories:**
  - **Conjunction-class missions** have long stays at Mars (500+ d); longer mission durations (950+ d); smaller propulsive delta-v requirement; and similar transit times (~210 d) both ways
  - **Opposition-class missions** have short stays at Mars (30-50 d); shorter mission durations (~700 d); larger propulsive delta-v requirement; and dissimilar transit times (~210 d outbound and ~400 d back)

- **A nuclear thermal propulsion (NTP) or nuclear electric propulsion (NEP) system can be enabling for opposition-class (short-stay) missions, with the shortest total mission times**
  - The NEP configuration being studied is a NEP/chem hybrid with a LOX/methane stage

- **Detailed Mars mission analyses currently in progress are considering both NTP and NEP concepts; the agency has not yet down selected a Mars transportation architecture**
  - Nevertheless, **key technology maturation activities need to be performed now** to bring nuclear propulsion on line by the 2030s
  - **NTP key technologies** include nuclear fuel/element design and manufacturing; advanced reactor design; long-term liquid hydrogen storage; and fuel element and engine test capabilities/facilities
  - **NEP/chem key technologies** include nuclear fuel/element design and manufacturing; thermal-to-electric power conversion; very large deployable composite radiators; high-power electric propulsion thrusters; and long-term cryogenic oxygen and methane storage
  - **National Academy of Sciences study** has been initiated to evaluate NTP and NEP technology maturity, development approach, and applicability to Mars missions; concludes in Apr 2021

Space Nuclear Technologies Portfolio

The Space Nuclear Technologies Portfolio will mature technologies and demonstrate system capabilities to meet the power and propulsion needs for Artemis

- Prioritizes resources on near-term surface power needs and pursues system synergies and common technologies for space propulsion
- Advanced technologies for nuclear fuel and fuel element manufacturing and testing
- Establish conceptual designs for major subsystems
- Conduct trade studies to determine system performance requirements and key technology risks/needs
- Collaborate with DOD, DOE, industry, and academia

Major goals for nuclear fission power activities:

- Design and test a fission power system that can enable human exploration of Moon and Mars
- Collaborate with DOE & industry to initiate a project leading to a capability demonstration on Moon in the 2027 timeframe

Major goals for nuclear propulsion activities:

- Investigate the extent to which DOD and DOE common fuel development interests and production capabilities can be leveraged
- Mature fuel, fuel element, and reactor materials and manufacturing technologies
- Design and develop required subsystem and system test capabilities/facilities
- Establish appropriate scope, budget, and schedule for a flight demonstration in the late 2020s

	FY21	FY22	FY23	FY24	FY25
Space Nuclear Power and Propulsion	**100.0**	**142.4**	**168.1**	**190.0**	**256.8**
Nuclear Fission Power	62.1	107.4	118.1	125.0	149.8
Nuclear Propulsion	37.9	35.0	50.0	65.0	107.0

NASA/DOE Nuclear Fission Power Design Study

NASA and DOE are collaborating on a study to define a fission power system concept for a class flight demonstration to the Moon in 2027 timeframe, with extensibility to human Mars missions. Final report is due in March.

NASA primary responsibilities:
- Power conversion
- Heat rejection
- Power management & distribution
- Lander integration
- Mission concept of operations
- Launch approval

DOE primary responsibilities:
- Reactor module
- Reactor controls
- Radiation shielding
- Transportation logistics
- Pre-launch site testing
- Safety
- Security

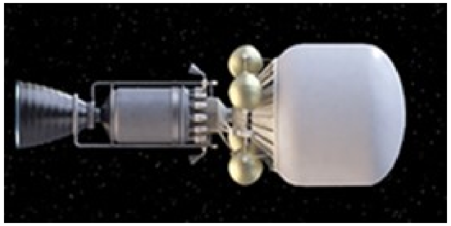
Joint responsibilities:
- System integration & interfaces
- Primary heat transport
- Power system concept of operations
- Flight certification
- Communication strategy
- Industry & commercial partnerships
- Cost & schedule

The study final report will include:
- TRL assessment and technology maturation plan
- Comparison of reactor fuel options (including LEU & HEU)
- System mass analysis relative to 2000 kg target
- Packaging concepts for lunar lander and deployment
- Radiation dose vs distance sensitivity analysis
- Analysis of reactor maximum operating lifetime
- Analysis of core load-following characteristics
- Strategies for reactor processing and launch
- Hardware heritage description
- CAD models
- Full system mass with appropriate growth allowances
- Estimated development cost & schedule
- Development & programmatic risk assessment
- Acceptance and qualification test plans

NTP Flight Demonstration Studies Status Update

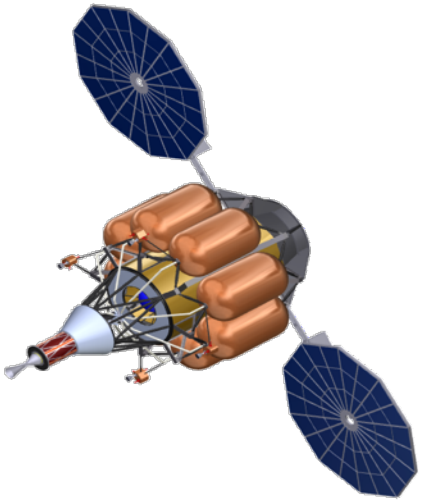
Two approaches to assessing flight demo scope and timing:

- “FD1” is a **schedule-driven** approach examining what could be done by 2024-2025
- “FD2” is a **capability-driven** approach assessing the demonstration scope and timing that best matures technologies and retires risks relevant to the eventual NTP flight system
- In each case, demonstration concepts are accompanied by schedule and cost projections, and the results are peer reviewed and documented



FD1 result:

- A flight demonstration that might be executable by 2024-2025 would rely on existing technologies and be executed at a non-representative scale. **It would retire essentially no technical risk and have no extensibility to the Mars architecture**, despite an estimated cost approaching $1 B.
- The assessment was made by a multi-center NASA team; the result did not warrant further examination by an industry team



FD2 progress:

- This scenario is being assessed by separate NASA-led and industry-led teams; both studies are past their midway points and should be finished by April
- The industry study team, led by Analytical Mechanics Associates, includes Aerospace Corporation, Aerojet Rocketdyne, Blue Origin, Boeing, BWX Technologies, General Atomics, United Launch Alliance, Ursa Major, Ultra Safe Nuclear Corporation, and Xenergy

Space Nuclear Power and Propulsion Summary

Space nuclear power and propulsion can enable robust exploration of Moon and Mars

- Fission surface power systems can provide abundant and continuous power in all environmental conditions in a less massive and more reliable implementation than solar power system
- Fission propulsion systems can enable the shortest total mission times to Mars and can enable the most challenging mission scenarios (such as opposition-class trajectories)

Key fission surface power technologies are needed soon to support lunar missions and are ready for initiating a flight demonstration

- STMD will collaborate with DOE and industry to design, fabricate, and test a fission power system that can enable human exploration of Moon and Mars

Key fission propulsion technologies need additional development and validation prior to undertaking a flight demonstration with extensibility to Mars transportation

- NTP technology maturation needs include fuel/element design and manufacturing; high-temperature reactor design; cryogenic propellant management; and test capabilities/facilities
- NEP technologies maturation needs include fuel/element design and manufacturing; power conversion; deployable composite radiators; high-power thrusters; and cryogenic propellant management
- STMD will continue to the mature key technologies needed for nuclear propulsion systems while completing the assessment of the appropriate scope and timing of a flight demonstration

STMD will mature technologies and demonstrate system capabilities to meet the power and propulsion needs for Artemis

Go

Rapid, Safe, & Efficient Space Transportation

Solar Electric Propulsion (SEP)

Nuclear Propulsion Technologies

Thruster Advancement for Low-temperature Operations in Space (TALOS)

Cryogenic Fluid Management

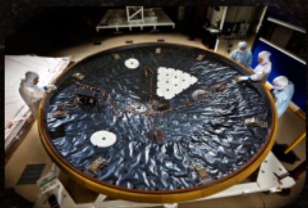
Green Propellant Infusion Mission (GPIM)

Rapid Analysis and Manufacturing Propulsion Technology

- Enable Human Earth-to-Mars Round Trip mission durations less than 750 days.
- Enable rapid, low cost delivery of robotic payloads to Moon, Mars and beyond.
- Enable reusable, safe launch and in-space propulsion systems that reduce launch and operational costs/complexity and leverage potential destination based ISRU for propellants.

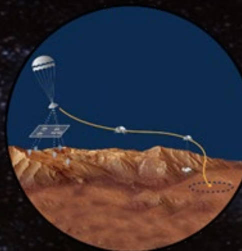
Land

Expanded Access to Diverse Surface Destinations



Mars Science Laboratory Energy Descent and Landing Instrument (MEDLI 2)

Navigation Doppler LIDAR



Terrain Relative Navigation

Mars Entry Descent and Landing

Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID)

Safe and Precise Landing – Integrated Capabilities Evolution (SPLICE)

- **Enable Lunar and Mars Global Access with land large (on the order of 20 ton) payloads to support human missions.**
- **Land Payloads within 50 meters accuracy while also avoiding local landing hazards.**

Entry, Descent and Landing (EDL)

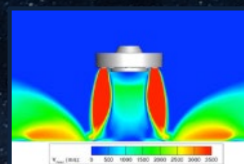
Lunar Capabilities (feeding forward to Mars)

Precision Landing and Hazard Avoidance

Safely and precisely land near science sites or pre-deployed assets

Plume Surface Interaction

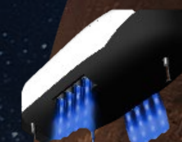
Reduce lander risk by understanding how engine plumes and surfaces behave



Mars Capabilities

Large Scale Demonstration

Large structures, including deployables, that can deliver high-mass payloads (LOFTID)



Data Return and Model Improvements

Measure entry system performance and update unique, critical simulations for Moon and Mars; modeling for supersonic retro-propulsion

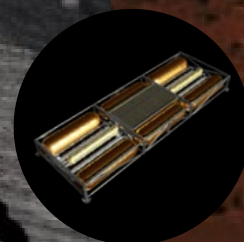
- Landing safely within 10 to 100 m of key science and resource sites and pre-deployed assets, to enable sustainable human presence. Capabilities (sensors, computing) demonstrated at the Moon feed directly forward to Mars.
- Understanding the phenomena of Lunar and Martian landing vehicle plumes will reduce risk for all landers and nearby assets. Engine plumes induce environments on the lander that must be considered in design. Modeling and ground test techniques feed forward to Mars.
- Gathering EDL-relevant flight data at every opportunity is critical for validating models, and complements ground tests. EDL relies on simulations for end-to-end capabilities that cannot be fully tested on Earth. Applications: Lunar Deorbit, Descent, Landing, and Ascent (DDL&A), Mars EDL, all planetary entries, and Earth return of crew, assets, or samples.

Live

Sustainable Living and Working Farther from Earth

In Space Manufacturing

Regenerative Fuel Cells

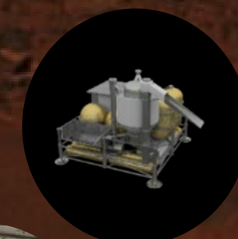


Astrobee

Surface Power

Synthetic Biology

In-situ Resource Utilization (ISRU)

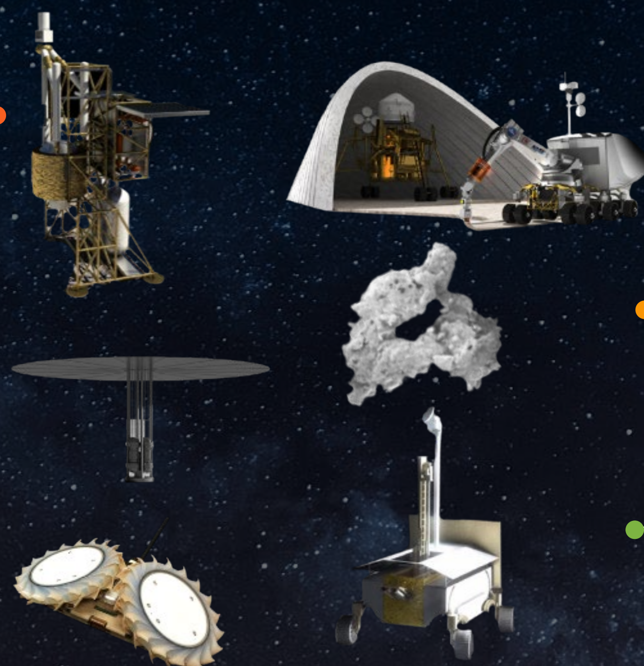


Integrated Systems for Autonomous Adaptive Caretaking

- Conduct Human/Robotic Lunar Surface Missions in excess of 28 days without resupply.
- Conduct Human Mars Missions in excess of 800 days including transit without resupply.
- Provide greater than 75% of propellant and water/air consumables from local resources for Lunar and Mars missions.
- Enable Surface habitats that utilize local construction resources.
- Enable Intelligent robotic systems augmenting operations during crewed and un-crewed mission segments.

Note: Mid TRL and High TRL Technology Development for Life Support and EVA suits are HEOMD Responsibility

Lunar Surface Innovation Initiative (LSII)



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

Surface Excavation & Construction

Enable affordable, autonomous manufacturing or construction

Lunar Dust Mitigation

Mitigate lunar dust hazards

Extreme Environments

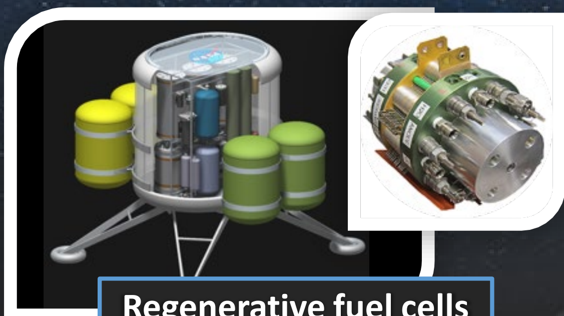
Enable systems to operate through out the full range of lunar surface conditions

- **Accelerate technology readiness for key lunar infrastructure capabilities enabling technology demonstrations for early un-crewed commercial missions, as well as informing development of crewed flight systems.**
- **Implement through a combination of in-house activities, competitive programs, and public-private partnerships.**
- **Coordinate with NASA's Science Mission Directorate and Human Exploration and Operations Mission Directorate to identify priorities.**

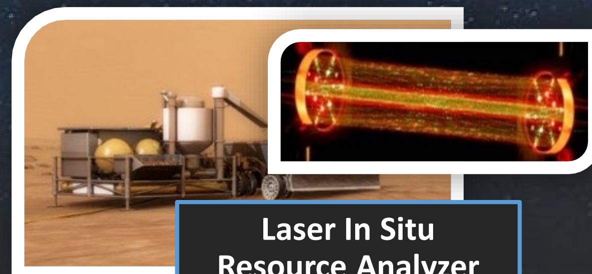
Mars Surface Technologies

Lunar Surface Technologies
- Volatile extraction
- Water electrolysis
- Gas liquefaction
- Cryo fluid management and storage
- LOX-based propulsion
- Entry, Descent & Landing
- Surface Power

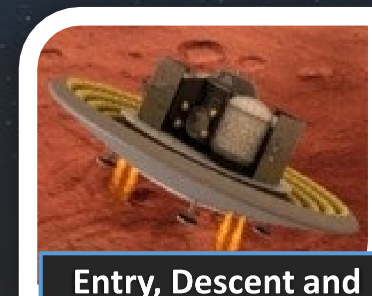
Mars Surface Technologies
- Atmosphere processing
- Solid oxide electrolysis
- Gas liquefaction
- Cryo fluid management and storage
- LOX-based propulsion
- Entry, Descent & Landing
- Surface Power



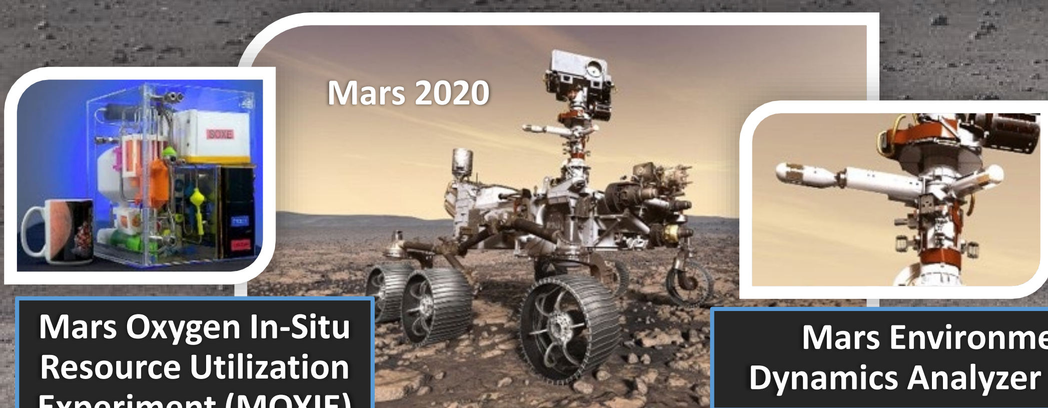
Regenerative fuel cells are an integral part of surface power



Laser In Situ Resource Analyzer



Entry, Descent and Landing



Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE)

Mars Environmental Dynamics Analyzer (MEDA)

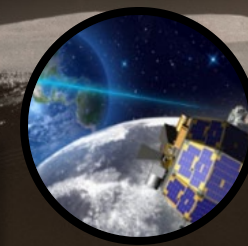
Nuclear Surface Power

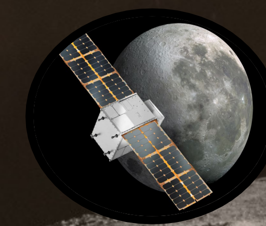
Explore

Transformative Missions and Discoveries

- Enable new discoveries at the Moon, Mars and other extreme locations.
- Enable new architectures that are more rapid, affordable, or capable than previously achievable.
- Enable new approaches for in-space servicing, assembly and manufacturing.
- Enable next generation space data processing with higher performance computing, communications and navigation in harsh deep space environments.

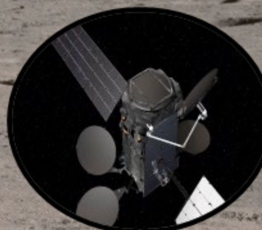
Laser and Optical Communications

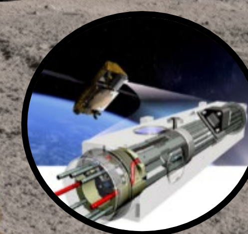




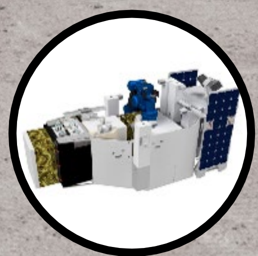
CAPSTONE

SPIDER





Atomic Clock



Archinaut

Bulk Metallic Glass Gears

Surface Robotic Scouts

OSAM-1 (Satellite Servicing & SPIDER)

Objectives

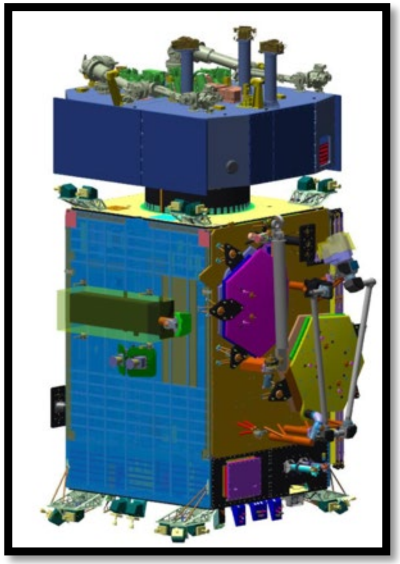
- On-orbit Servicing Assembly and Manufacturing 1 (OSAM-1) combines satellite servicing and SPace Infrastructure DExterous Robot (SPIDER) objectives to qualify advanced technologies that enable on-orbit satellite life extension.
- Completes critical servicing technologies through ground-based qualification before transitioning to U.S. industry
- Technology areas to be qualified include several components of the navigation system, servicing avionics and software, robot arm and software elements, and tool drive system and tools

Status

- Completed seven Subsystem CDRs
- Completed Spacecraft CDR, Ground System CDR
- Completed SPIDER PDR
- Achieved Kodiak Lidar TRL 6
- Servicing Payload Engineering Development Units test and risk mitigation on-going
- Conducted the Fourth Technology Transfer Industry Day, renamed to OSAM Tech Transfer Day

Deliverables/Schedule

- Complete CDRs for SPIDER, and remaining subsystems FY21
- Mission CDR September 2020
- Critical servicing technologies ground qualified FY22/23
- SPIDER payload targeting delivery to spacecraft bus for integration and test in FY23



Maxar SPace Infrastructure DExterous Robot (SPIDER)

Objectives

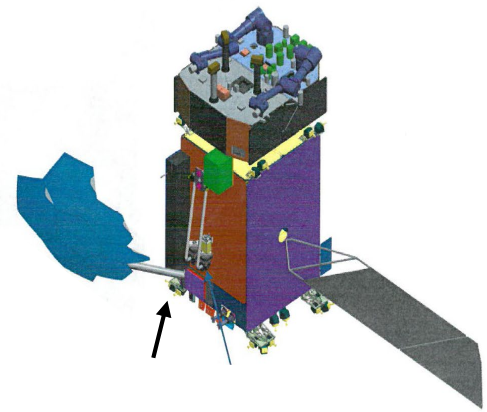
- Demonstrate technologies needed for in-space manufacturing and on-orbit assembly for long term exploration of the Moon and Mars
- Manufacture a 10 meter boom and assemble a 3 meter antenna to demonstrate the robotic build of large in-space structures that exceed next generation launch vehicle fairing size
- Technologies developed under SPIDER could enable entirely new architectures and space infrastructure for a wide range of Government and commercial missions, including commercial satellites

SPIDER Status

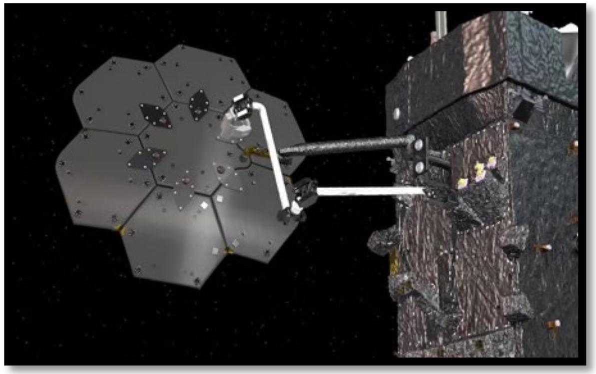
- Completed Phase 2 Kickoff, Systems Requirements Review, Manufacturing Payload PDR, Modular Antenna Assembly PDR
- Agreement on implementation of external ops center for SPIDER operations

Deliverables/Schedule

- FY21: Critical Design Review
- FY21: SPIDER Integration and Test
- FY23: SPIDER Integration with the Maxar Spacecraft Vehicle
- FY24: Launch, Mission Operations



Space Infrastructure Dexterous Robot (SPIDER) Payload (Maxar Build, Ops)



STMD Opportunities for Academia and Industry

STMD anticipates awarding ~$600M to academia and industry supporting 2020 solicitations & awards *

- **STMD Tipping Point Multiple Awards:** ***January – March 2020*** — $250M
- **Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR) Phases I, II, II-E, Civilian Commercialization Readiness Pilot Program (CCRPP), Sequential:** ***Phase I Solicitation January – March 2020*** — $212M
- **Announcement of Collaborative Opportunity (ACO):** ***January – March 2020*** — $10M
- **Flight Opportunities Tech Flights:** ***Feb – April 2020*** — $10M
- **Early Career Faculty (ECF):** ***Feb – March 2020*** — $6M
- **Early Stage Innovations (ESI):** ***April – July 2020*** — $9M
- **NASA Innovative Advanced Concepts (NIAC) Phases I, II, III:** ***Phase I Solicitation June – July 2020*** — $4M
- **NASA Space Technology Graduate Research Opportunities (NSTGRO):** ***September – November 2020*** — $19M
- **Space Technology Research Institutes (STRI):** ***May – July 2020*** — $30M
- **SmallSat Technology Partnerships (STP):** ***Sept – Nov 2021*** — $3M
- **Centennial Challenges:** ***Varied release dates*** — $8M
- **NextSTEP Broad Agency Announcements (BAAs):** ***Varied release dates*** — *Varies*
- **Lunar Surface Technology Research (LuSTR) Opportunities:** ***Coming soon!!!*** — $30M

Note: Funding awards are approximate and subject to change

- Green: Open Solicitations as of Feb 28, 2020
- Blue: Solicitations will be open *in the timeframe specified in italics*

** Note: All opportunities reflected are contingent upon appropriations approval*

Space Technology Research Grants *Opportunities to Propose*

Engage Academia: *tap into* ***spectrum*** *of academic researchers, from graduate students to senior faculty members, to examine the theoretical feasibility of ideas and approaches that are critical to making science, space travel, and exploration more effective, affordable, and sustainable.*

NASA Space Technology Graduate Research Opportunities (NSTGRO)

- Graduate student research in space technology; research conducted on campuses and at NASA Centers and not-for-profit R&D labs

Early Career Faculty (ECF)

- Focused on supporting outstanding faculty researchers early in their careers as they conduct space technology research of high priority to NASA’s Mission Directorates

Early Stage Innovations (ESI)

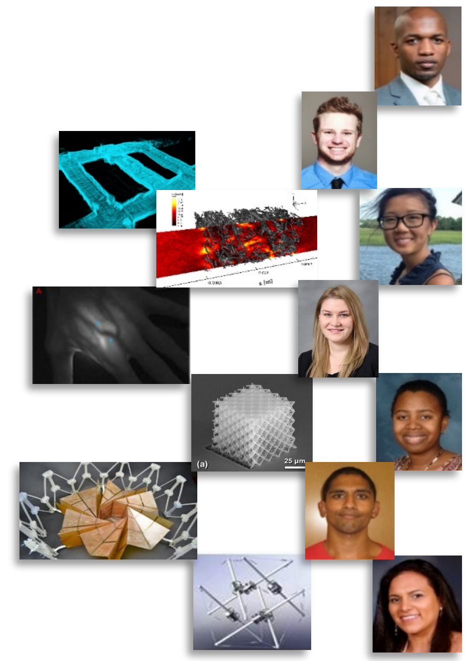
- University-led, possibly multiple investigator, efforts on early-stage space technology research of high priority to NASA’s Mission Directorates
- Paid teaming with other universities, industry, and non-profits permitted

Lunar Surface Technology Research (LuSTR) Opportunities

- University-led efforts addressing high priority lunar surface challenges
- Short duration, high value grants with emphasis on potential infusion
- Paid teaming with other universities, industry, and non-profits encouraged

Space Technology Research Institutes (STRI)

- University-led, integrated, multidisciplinary teams focused on high-priority early-stage space technology research for several years



Accelerate development of groundbreaking high-risk/high-payoff low-TRL space technologies

SBIR/STTR Program Strategy: Moon to Mars

SBIR·STTR
America's Seed Fund™
POWERED BY NASA

- The 2020 SBIR/STTR solicitation released on January 21 emphasizes topics on long-term human exploration and space utilization consistent with the Moon to Mars Campaign.
- Two legislative proposals to increase CCRPP awards to $10M and allow direct Phase II authority have been submitted for consideration in the reauthorization process in order to facilitate NASA's ability to land humans on the Moon in 2024.
- Up to ~$20M of the FY20 increase will be used to continue development of existing technologies related to the Moon to Mars objectives through our Phase II Sequential Program, with award amounts up to $5M. NASA is in final negotiations with the SBA for a policy waiver. These awards will be managed under our SST and GCD programs.
- Currently there are multiple technologies in our SBIR/STTR portfolio that can be activated through Phase IIIs and our post-Phase II vehicles to address the Moon to Mars goals
- FY21 onward we will continue to include content in our annual solicitation as well offer opportunities through our post-phase II vehicles to target the Moon to Mars goals.

In order to support the Moon to Mars initiative, the SBIR/STTR Program has drafted the following to request changes to our authority

Legislative Proposals

Increase maximum CCRPP award to $10M and funding cap to 20% of SBIR budget

Allow direct to Phase II authority

Policy Waiver for SBA

Increase maximum Phase II Sequential award to $5M and allow Sequential awards that are larger than the initial Phase II amount

Sampling of Industry and OGA Participants in Exploration Technology

BWXT
BWX Technologies, Inc.
MAXAR TECHNOLOGIES
exos Aerospace
ORBITBeyond
Delivering to the Moon
CUBIC AEROSPACE
AEROJET ROCKETDYNE
MADE IN SPACE
Los Alamos NATIONAL LABORATORY EST. 1943
MOON EXPRESS
FRONTIER AEROSPACE
NEVADA NATIONAL NNSS SECURITY SITE
GeoOptics
FIREFLY AEROSPACE
CUA
WORLD VIEW
Masten
CFD RESEARCH
ASTROBOTIC
SPACEX
FREEDOM PHOTONICS
Cornerstone RESEARCH GROUP
RAVEN AEROSTAR
zero G
Virgin Galactic
air squared
TETHERS UNLIMITED
NORTHROP GRUMMAN
nanocomp TECHNOLOGIES, INC.
Honeywell
PARAGON SPACE DEVELOPMENT CORPORATION
Advanced SPACE
Ball
Space Lab Technologies, LLC
ULA
United Launch Alliance
Tyvak
ExoTerra
IC2
LUNA
PIONEER ASTRONAUTICS
OPTERUS RESEARCH AND DEVELOPMENT, INC.
ROBUST ANALYTICS
BOSTON MICROMACHINES CORPORATION
INNOVATION Labs, Inc.
A Research and Innovation Company
BOEING
CAC
Connecticut Analytical Corporation
Viasat
CDI
ALPHACORE
IOS
INTELLIGENT OPTICAL SYSTEMS, INC.
BUSEK
Space Propulsion and Systems
ATAC
AGNC
SINCE 1986
IAI
Intelligent Automation, Inc.
BNS
DRAPER
Lynntech
Composites Automation LLC.
anasphere
BRM
Bally Ribbon Mills
PSI Physical Sciences Inc.
MT
MOSAIC ATM
X-WAVE INNOVATIONS, INC.
Make state-of-the-art obsolete
SNC SIERRA NEVADA CORPORATION
QORTEK
TDA RESEARCH
QUEST THERMAL GROUP
UP
AEROGEL technologies
VOXTEL OPTO
QSI
QUALTECH SYSTEMS INC.
LOCKHEED MARTIN
Integrated Spaceflight Services
Creare
ASRC
ROCCOR
CPE
SPIRIT AEROSYSTEMS
USNC
ULTRA-SAFE-NUCLEAR
Virgin Orbit
DSS
digital surveillance systems
NSC
Near Space Corporation
INTUITIVE MACHINES
FIBERTEK, INC.

STMD By The Numbers (FY 2019)

>3,500
Proposals Evaluated

>1,000
Active Technology Projects

>700
Proposals Selected

>2,300
Software Releases

>350
University Partnerships with >100 Universities

>400
Industry Collaborators

>50
Projects Leading to Flight Demonstrations

>900
Transitions since 2011


NASA
EXPLORE SPACE TECH
TECHNOLOGY DRIVES EXPLORATION

Additional
Theme/Program Level Information

Cryogenic Fluid Management (CFM) Technologies

Demonstrate technologies enabling autonomous transfer and storage of cryogenic hydrogen, capable of scaling to tens of metric tons, with negligible losses for long duration in space and on the lunar surface.

Technology Gaps

- LOX/Methane CFM - Zero Boil Off and Liquefaction at Low Power (100’s Watts @ 90K)
- Zero-g Cryo Storage & Transfer (LOX, LCH4, LH2)
- Advanced Cryocoolers
- Improved Vacuum Insulation Systems
- Transfer Operations
- Zero-g Fluid Modeling

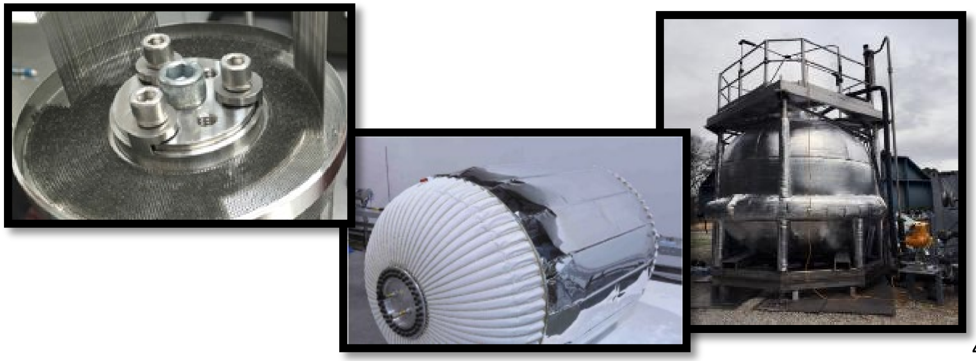
Current CFM component development work:

- HLS BAA Refueling Studies
- Cryogenic thermal coatings
- Automatic Cryo-couplers
- Low Conductivity Structures (SHIIVER tank)
- Propellant Densification
- High Vacuum MLI (IFUSI and CELSUIS)
- Vapor Cooling (eCryo)
- Unsettled liquid mass gauging (RRM-3)
- Low Leak Valves
- High Capacity Cryocooler (20K 20W)
- 90K Cryocooler development

Future Mission Planning:

Demonstrate enabling technology for a propellant refueling and storage needed for both lunar sustainability and Mars Transit Integrated demo, including, but not limited to the following technologies:

- Autogenous pressurization
- Multilayer Insulation
- 90 K Cryocoolers
- Tube-on-tank heat transfer
- Unsettled Mass Gauge
- Thermodynamic Vent
- Transfer Operations
- Line-chilldown & 2 phase flow meter
- Automated Cryo-coupler



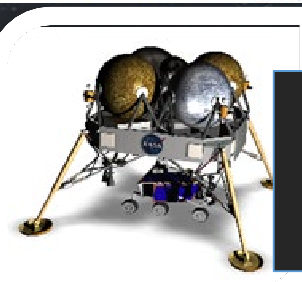
Cryogenic Fluid Management

HLS Refueling Studies

The Evolvable Cryogenics (eCryo) project

ULA H2/O2 Thruster development

Cryogenic Fluid Transfer Technology Demo Con-ops development with SpaceX



Lunar CFM Studies and Cryocooler Development with Lockheed Martin

Intuitive Machines: “Utilize NASA’s Radio Frequency Mass Gaging System for first flight”

Cryocooler Development enabling zero boil-off with Creare

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

Evolvable Cryogenics (e-Cryo)

Objectives:

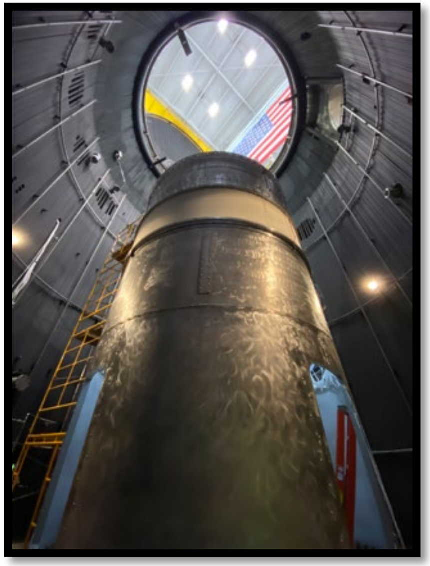
- Yield knowledge that can be used to reduce cryogenic fluid mass/margin, and integrated system mass while maximizing utility of cryogenic fluids
- Demonstrate integrated approach to thermal management, fluid measurement, and development of flight-like instrumentation and components
- Develop techniques to enable modeling of large in-space cryogenic fluid systems
- Assess feasibility of Integrated Vehicle Fluids (IVF) for SLS Exploration Upper Stage

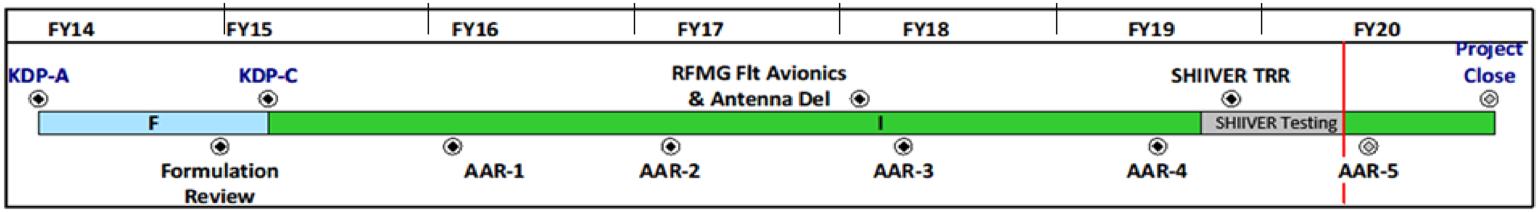
Current Status:

- Completed all SHIIVER thermal and acoustic testing. Initial boil off and vapor cooling performance met the goal of a 15% reduction in boil off.
- Continue development of multi-node and Computational Fluid Dynamics (CFD) analysis tools
- Continue to acquire Radio Frequency Mass Gauge (RFMG) monthly data on Robotic Refueling Mission-3 (RRM-3) payload to demonstrate sensor survivability in space conditions

Deliverables/Schedule

- FY20: Complete SHIIVER test campaign and deliver final analysis tools & reports





Solar Electric Propulsion (SEP)

Objectives:

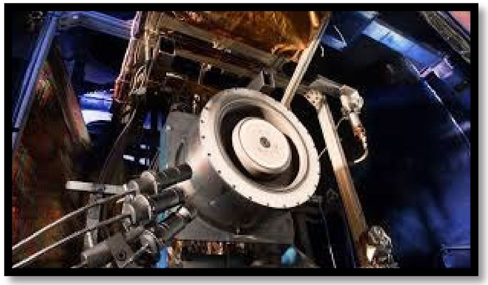
- Characterize performance of a high-power (12 kW) Solar Electric Propulsion system
- Demonstrate and qualify SEP for use in Gateway Power and Propulsion element

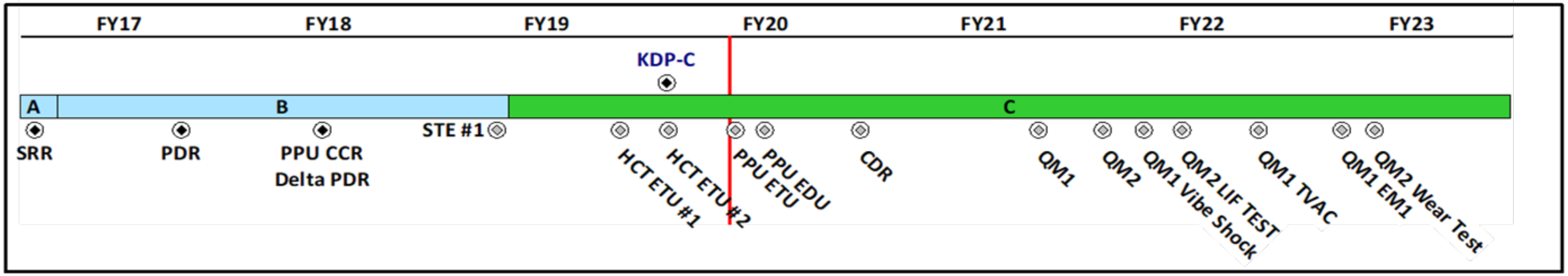
Current Status:

- Two engineering test unit 13 kW Hall current thrusters are currently undergoing development testing to demonstrate the design will perform in the intended flight regime. Both thrusters have performed well at 12 kW output consistent with predictions
- The Power Processing Unit and Xenon Flow Controller engineering units are completing development and acceptance test completion and delivery to GRC to support hot fire wear testing

Deliverables/Schedule

- FY19: Completed KDP-C and build/hot-fire of the first engineering unit Hall current thruster
- FY20: Complete engineering development tests of the SEP strings and complete Critical Design Review.
- FY21: Complete build of qualification units and begin testing



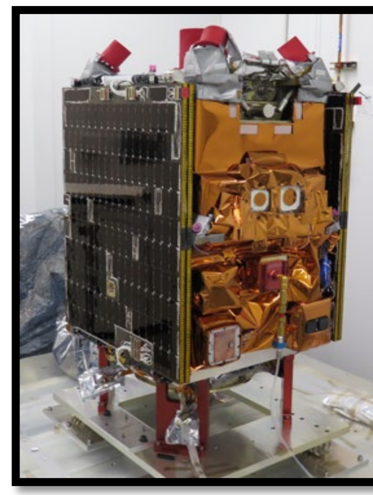


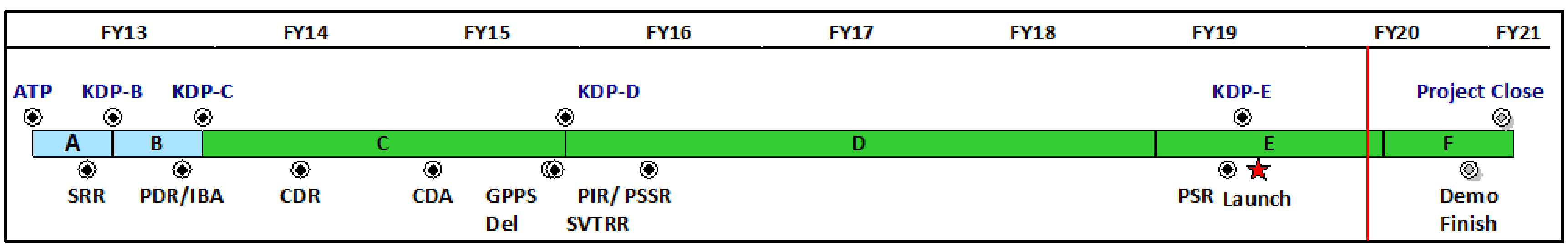
Green Propellant Infusion Mission (GPIM)

Objectives:
- Demonstrate the on-orbit performance of a complete AF-M315E propulsion system suitable for an ESPA-class spacecraft
- Demonstrate AF-M315E steady-state performance of delivered volumetric impulse at least 40% greater than hydrazine

Current Status:
- Satellite is on-orbit – launched on STP-2 mission June 25, 2019
- Spacecraft bus on orbit commissioning is complete and green propellant propulsion system performance testing is on-going
  - All spacecraft systems checked out and performing nominally
  - Propulsion system has performed nominally
  - Satellite attitude control using only thruster firing has been successfully demonstrated
  - The first major orbit lowering extended thruster burn was successfully accomplished – two more orbit-lowering burns are planned before March 2020

Deliverables/Schedule
- Post-flight report – due ~September 2020





Archinaut (OSAM-2)

Made In Space Archinaut One

Objective:

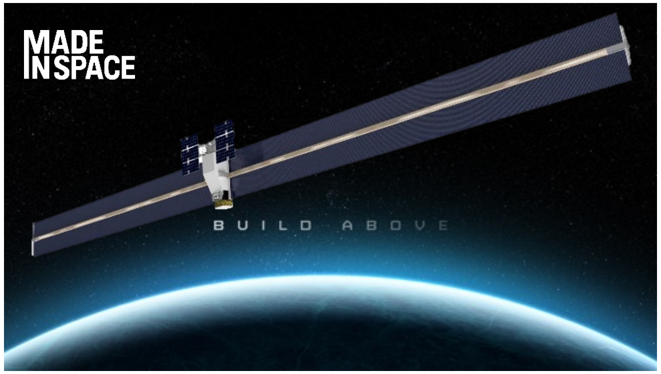
- Demonstrate robotic manipulation of spacecraft hardware and additive manufacturing of extended structures to deploy two 10 square meter solar arrays in a technology demonstration flight mission

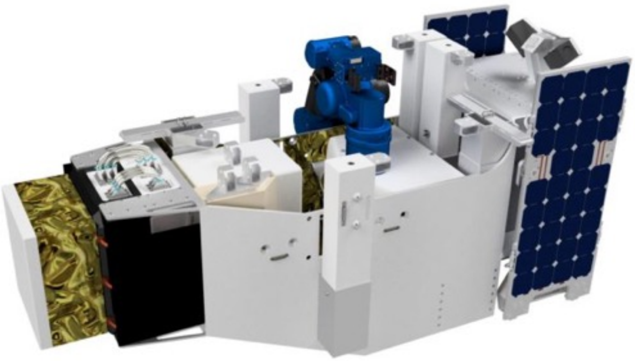
Current Status:

- Successfully completed System Requirements Review and Mission Definition Review (Q1FY20)
- Subsystem design reviews and testing underway

Schedule:

- Preliminary Design Review (Q2FY20)
- Critical Design Review (Q1FY21)
- Operational Readiness Review (Q3FY22)
- Pre-Ship Review/Flight Readiness Review (Q4FY22)
- Launch aboard SpaceX Falcon 9 via SmallSat Rideshare Program (Q4FY22)
- Perform technology demonstration and monitor beam/solar array status as part of one-year mission (Q4FY23)



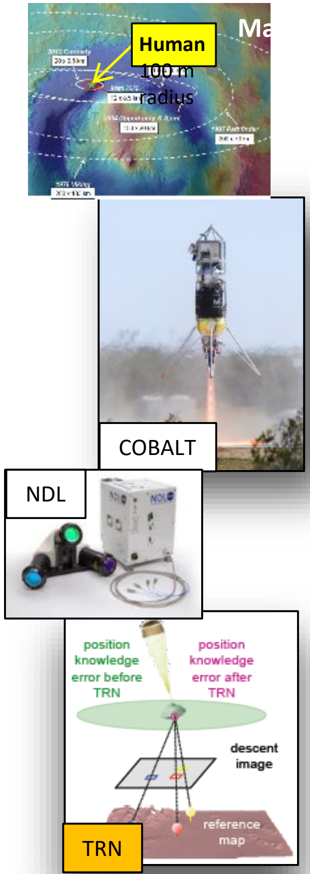


Precision Landing and Hazard Avoidance (PL&HA)

Key Challenge: Improve landing precision on the Moon, feeding forward to Mars, to within 10 to 100 meters. Detect and avoid hazards (natural and manufactured) to support human-rated reliability levels.

Integrated Strategy:

- Mature individual components (sensors, computing, algorithms), conduct integrated tests via the SPLICE (Safe and Precise Landing- Integrated Capabilities Evolution) and multiple Tipping Point projects, infuse into near-term (2024-26) robotic Lunar Demonstrations, and commercialize:
  - ➢ Mature Navigation Doppler Lidar (NDL) velocimeter to TRL6 & suborbital test on Blue Origin New Shepard (2020), infuse on CLPS (2021), then on human Lunar landers via commercial partner Psionic
  - ➢ Commercialize Terrain Relative Navigation (TRN) after NASA Mars 2020 (TRL 9) system via: SPLICE investment in Draper TRN for New Shepard test (2020); and, Astrobotic TRN Tipping Point investment (2019-21)
  - ➢ Mature Hazard Detection System (HDS) to TRL5 (2020), test in Earth-based Flight Opportunity (2021), demo on CLPS (2023), then on human Lunar landers
  - ➢ Develop Descent & Landing Computer (DLC) with HPSC surrogate to TRL5 & suborbital test on Blue Origin New Shepard (2020), integrate HPSC in 2023/24, infuse on CLPS in 2024, then on human Lunar landers
- Develop descent and landing performance simulations and trade studies for candidate robotic and human missions to inform NASA technology investments (and timing) and inform technology infusion/transition to commercial partners (via Tipping Points, ACOs, and HLS Appendices)
- Forming cross-directorate/project partnerships for technology development and infusion synergy
  - ➢ Leverage Flight Opportunities & commercial Lunar landers (via CLPS) for maturation to human-rated missions



NOTE: Orange feeds forward to Mars

Safe & Precise Landing – Integrated Capabilities Evolution (SPLICE) Technology Overview

Objective

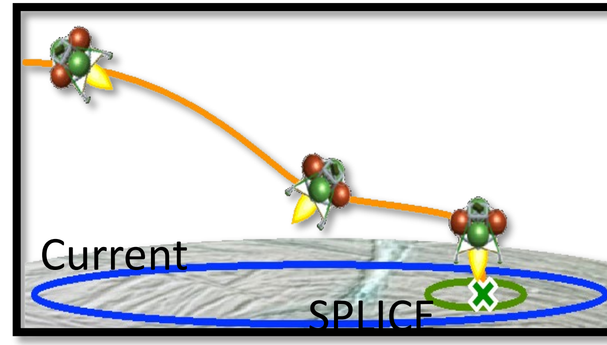
- Technologies that enable landing within 10 to 100 meters of targeted surface locations, including landing in close proximity to pre-positioned surface assets for robotic and human exploration. Current landing capabilities put these assets on the ground within kilometers of the targeted surface sites

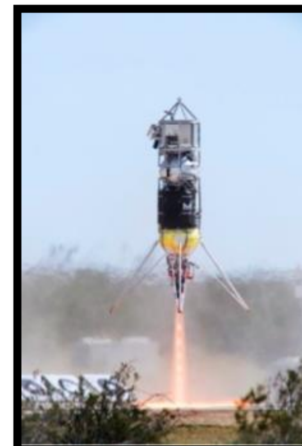
Current Status

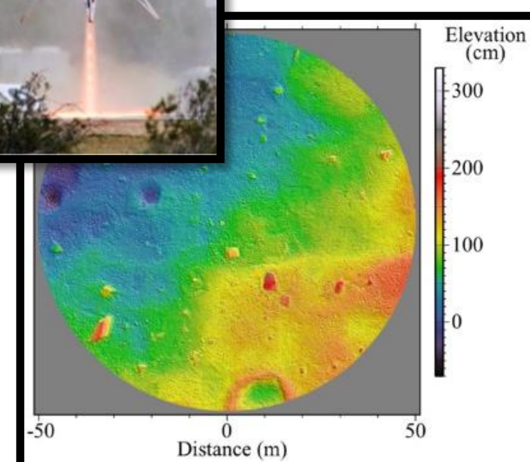
- Masten suborbital rocket flight of Lunar Terrain Relative Navigation (TRN) system completed in FY 2019
- Navigation Doppler Lidar (NDL) Engineering Test Units (ETUs) on track for FY 2020 completion and delivery to CLPS vendors for 2021 lunar flights
- Descent & Landing Computer (DLC) engineering development unit (EDU) with HPSC surrogate on track for FY 2020 completion
- Blue Origin New Shepard suborbital rocket flight tests of NDL ETU and DLC EDU on track for 2020

Deliverables/Schedule

- FY 2020: NDL ETU and DLC EDU complete flight test on Blue Origin New Shepard; Hazard Detection (HD) LIDAR EDU complete plus helicopter test
- FY 2021: Proceed with HD Lidar ETU and DLC ETU; further suborbital tests
- FY 2022: Completion of DLC ETU and HD Lidar ETU to TRL 6; CLPS flights of both in FY23/24







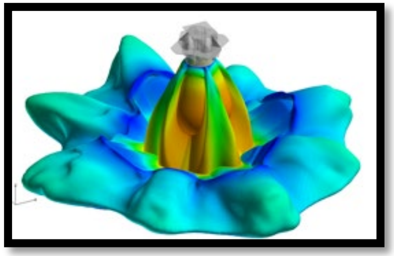
First Lunar Demonstration of Navigation Doppler LIDAR on CLPS in 2021

Plume Surface Interaction (PSI)

Key Challenge: Predict the descent engine plume and its effects on the lander vehicle and the planetary surface, including surface erosion and ejecta impacts, to reduce landing risk.

Integrated Strategy:

- **Improve, and quantify the uncertainty in, Plume Surface Interaction models by conducting ground tests to validate physics (for Moon, then feeding forward to Mars)**
  - Increase fidelity of experiments, from lab-scale unit tests to vacuum hot-fire tests with regolith, over 3-4 years
- **Leverage operational missions and technology demonstrations, to gather flight test data**
  - Mature flight instrumentation to acquire never-before-measured PSI phenomenon on CLPS, medium-sized landers, and human-scale Lunar landers.
  - Leverage descent cameras on Mars 2020 to view the surface during approach, and anchor models on CLPS lander in 2021
- **Apply improved models to lander designs and surface operations planning**
  - Factor the "induced environments" of the plume and ejecta into lander designs
  - Combine PSI tool with performance simulations to factor plume behavior into navigation sensors and landing risk.
  - Provide data on ejecta behavior to enable dust and asset damage mitigation on the surface
- **Utilize academia, small business, and other commercial partnerships to accelerate the pace of PSI knowledge**



NOTE: Orange feeds forward to Mars

Plume Surface Interaction (PSI) Technology Overview

Objective (FY20 project start)

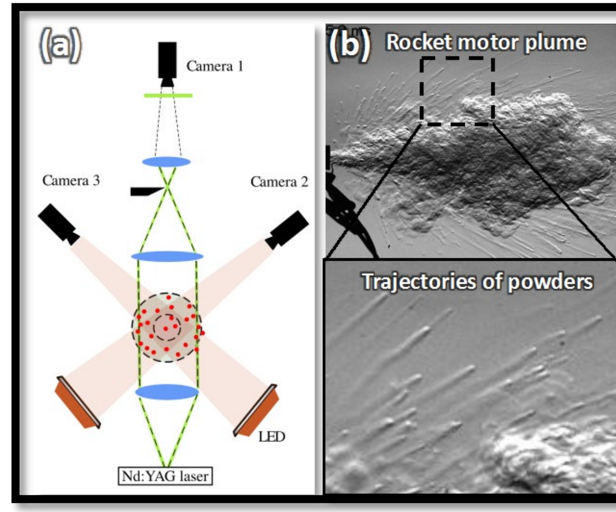
- Reduce lander risk by improving and validating Plume Surface Interaction models with high-fidelity data from both ground tests and flight instrumentation. Leverage all relevant flight opportunities

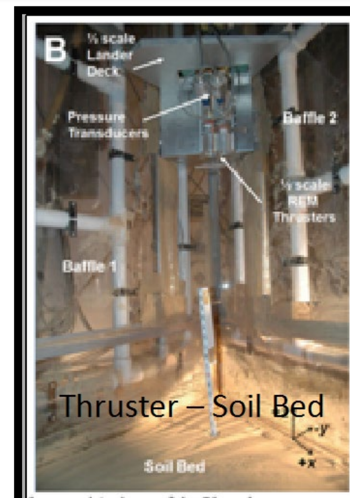
Current Status

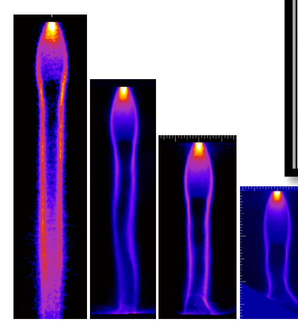
- Technical Interchange Meeting held with NASA Subject Matter Experts in early FY19
- Assessing and initiating complementary efforts in Early Stage Portfolio including solicitations and partnerships with industry and academia
- Establishing connections with Human Lander System (HLS), Lunar Dust Mitigation, industry, and Mars mission customers and partners
- Participating in developing stereo camera payload for CLPS
- Performed cratering reconstruction for InSight lander to exercise methods

Deliverables/Schedule

- FY20: windblown particle analysis in Planetary Aeolian Lab (ARC)
- FY21: Hot-fire engine test at MSFC; stereo camera data returned
- FY22: Instrumentation of CLPS lander for lander base and ejecta
- *Computational model update within 3-6 months of each test series; continuous application of tools to Lunar and Mars lander designs*







First ground test in 2020; First Lunar flight data from CLPS in 2021

LOFTID (Low-Earth Orbit Flight Test of an Inflatable Decelerator)

Objective

- Demonstrate Hypersonic Inflatable Aerodynamic Decelerator (HIAD) performance at the 6-m scale, at Mars-relevant heating conditions. Collect data to assess thermal and aerodynamic response

Current Status

- Co-Manifest with NOAA satellite JPSS-2 confirmed
- Successful Preliminary Design Review held June 2019
- Aeroshell and Rigid Structures Engineering Development Unit (EDU) testing complete
- Reentry Vehicle (RV) Subsystems EDU testing underway
- RV Subsystems Peer Reviews underway
- Rigid Structures Flight Hardware Build underway
- Partnership with SBIR company to include advanced gas generator

Deliverables/Schedule

- Critical Design Review: July 2020
- Avionics Integration Complete: February 2021
- System Test Complete: July 2021
- Reentry Vehicle Delivery to ULA: December 2021
- **Launch on Atlas V 401 from Vandenberg AFB: March 2022**

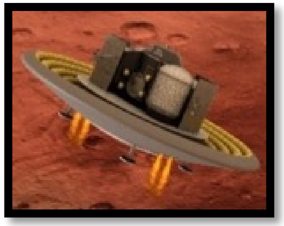
March 2022 LOFTID flight will be the largest heatshield ever flown.

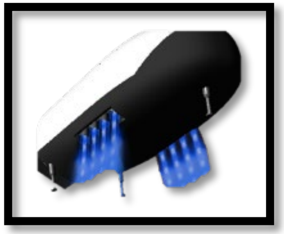
Mars Entry Descent and Landing (EDL)

Key Challenge: Land large (on the order of 20 ton) payloads safely (and precisely, see PL&HA) on the Mars surface in support of human exploration.

Integrated Strategy:

- **Builds on past Hypersonic Inflatable Aerodynamic Decelerator (HIAD) ground and flight demonstrations, and Mars EDL Architecture Study and the Descent Systems Study**
- **FY 2020--Demonstrate key technologies on Mars 2020 to inform future investments**
  - Terrain Relative Navigation: Allows the vehicle to determine position relative to the ground with an accuracy of approximately 200-feet (60-meters) or less; will provide capability to land near pre-deployed assets, avoid large scale landing hazards, and will reduce post-landing surface drive distances.
  - Mars Entry, Descent and Landing Instrumentation-2: Allows comparisons between analytical models and experimental data to reduce landing ellipse uncertainties and informs thermal protection system designs for future Mars missions.
- **Complete LOFTID, the Earth flight test of a 6-m scale inflatable decelerator with Mars-relevant heating**
- **Conduct design studies for a landing system capable of landing human-class payloads on Mars**





Partnerships:

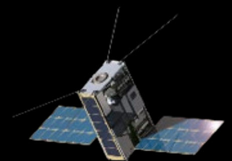
- United Launch Alliance (ULA) for LOFTID

Lunar ISRU Development and Demonstration Timeline

Reconnaissance, Prospecting, Sampling	Resource Acquisition & Processing	Pilot Consumable Production
Sub-system Demonstrations: Investigate, sample, and analyze the environment for mining and utilization.	*Follow The Natural Resources: Demonstrations of systems for extraction and processing of raw materials for future mission consumables production and storage.*	*Sustainable Exploration: Scalable Pilot Systems demonstrating production of consumables from in-situ resources in order to better support sustained human presence.*

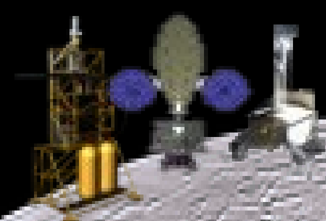
Oxygen from Regolith (Lunar Simulant) Ground Demos

Resource mapping cubesats: LunaH-Map, LunIR, Lunar IceCube & Lunar Flashlight.

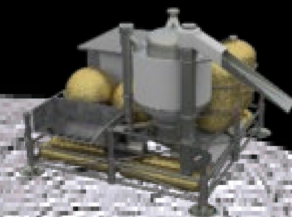


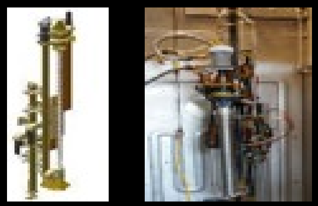
High-fidelity Lunar Simulant Production

ISRU Subsystem Consumables Extraction Demos and follow-on mapping missions



Scalable Pilot-ISRU Systems for Consumable Production



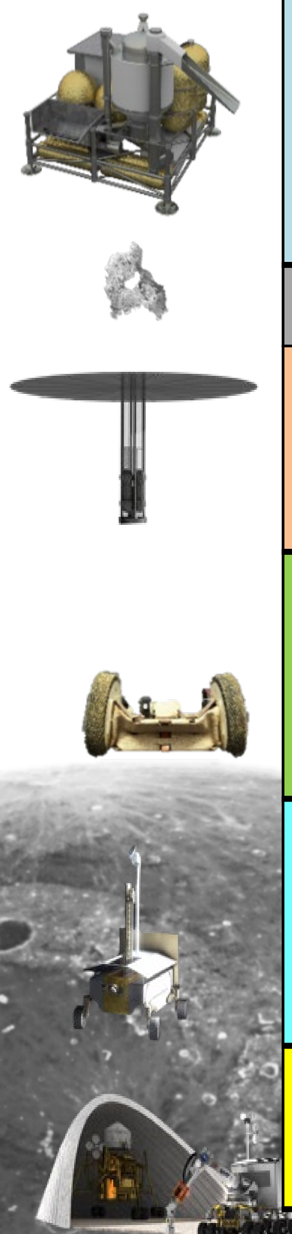


CLPS Drill Down-Select

Volatile characterization and mapping CLPS missions: PRIME-1 and VIPER

2019 → **203x**

Examples of Lunar Surface Innovation Initiative (LSII) Demonstrations



Capability Area	Activity	Flight Demo Timeline
ISRU	Polar Ice to Water Demonstration (includes Polar Resources Ice-mining Experiment -1)	CLPS FY22 (PRIME); FY24-26
	Regolith Extraction Processes & Technologies (O2 extraction, Ionic Liquids, Electrolyzer, Reactor)	FY20-23 Ground Dev; Flight FY24+
	Pilot ISRU Consumable Production Systems	FY28+
Dust Mitigation	Lunar Dust Mitigation Demonstrations (Materials, Mitigation technologies, etc.)	FY22+
Surface Power	Regenerative Fuel Cell	FY24+
	Regenerative Fuel Cell/PV Power	FY26+
	Chem Heat Int Power Source	FY24+
	Wireless Charging for Lunar Surface	FY26+
	Surface Power System Demonstrations	FY26+
Extreme Access	Surface Robotic Scouts Technology Demonstrations	FY24+
	Advanced Materials for Surface Suits	FY25+
	Technologies Enabling Exploration of Lunar Pits	FY24+
	Smart Video Guidance Center	FY22+
	Day/Night Lunar Rover Obstacle Avoidance	FY24+
	Lunar Surface Mobility Systems Demonstration(s)	FY26+
Extreme Environments	COLDArm	FY22/23
	Lunar Exposure Platform (Lunar MISSE)	FY22+
	Lunar Night and Material Survivability	FY22+
	Planetary & Lunar Environment Thermal Toolbox	FY23+
	Bulk Metallic Glass (BMG) for Rovers	FY23+
	Extreme Environments System Demonstration(s)	FY26+
Excavation & Construction	Robotic Excavation on Lunar Surface (Centennial Challenge)	FY19-21
	Lunar Surface Excavation Development & Demo	FY22+
	Lunar Surface Construction Development & Demo	FY27+

Polar Resources Ice Mining Experiment-1 (PRIME-1)

Objective
Develop a flight ready system that can assess the composition of regolith for water content and other volatiles at a polar lunar landing location.

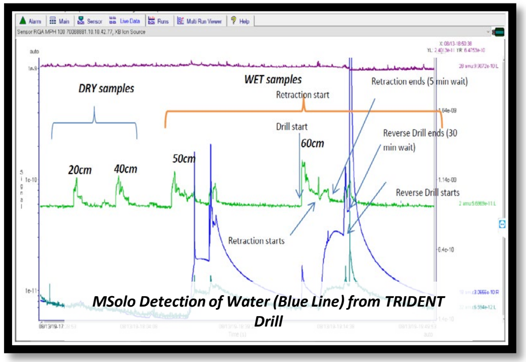
Description
PRIME-1 consists of two high-TRL subsystems; Mass Spectrometer observing lunar operations (MSolo) and The Regolith and Ice Drill for Exploring New Terrain (TRIDENT). These two subsystems will be integrated onto a commercial lunar lander for flight in 2022

Industry Participants
Honeybee Robotics is providing TRIDENT drill and Inficon will provide the mass spectrometer

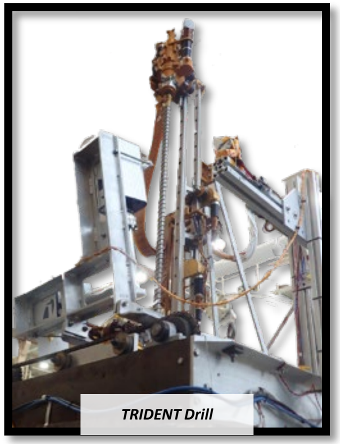
Current Status
- 8/6 – 8/27/2019: TRIDENT and Pvex drill testing at GRC
- 10/30/2019: Project delivered final report with TRIDENT drill selection
- 11/18/2019: Program held independent review and concurred with project's drill selection
- 4/2020: Preliminary Design Review of TRIDENT drill and Msolo mass spectrometer

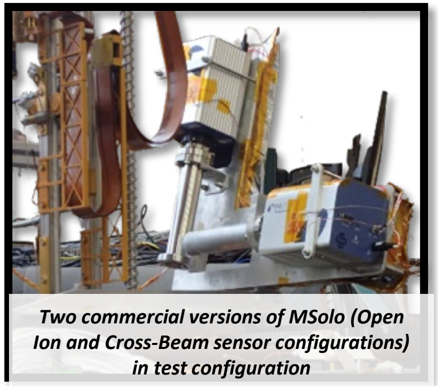
Deliverables/Schedule
- FY 2020: Complete Trident and Msolo Critical Design Reviews.
- FY 2021: Complete testing and delivery of spaceflight qualified hardware

Delivery of spaceflight qualified hardware for CLPS mission in 2023



MSolo Detection of Water (Blue Line) from TRIDENT Drill


TRIDENT Drill

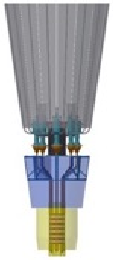

Two commercial versions of MSolo (Open Ion and Cross-Beam sensor configurations) in test configuration

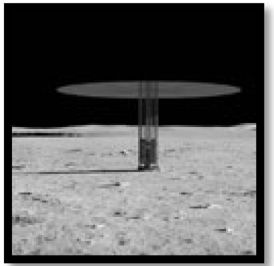
Lunar Surface Power

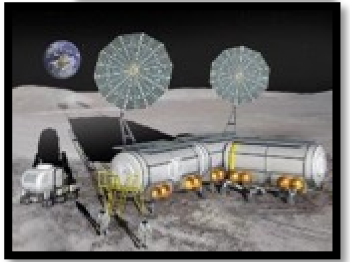
STMD is developing technologies which can provide the capability for continuous power throughout day and night for lunar and Mars Surface missions.

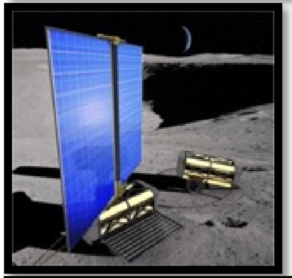
Technology Developments Underway:

- Power Generation
  - Lunar Surface Fission Power System: Flight reactor demonstration (2027)
  - Adaptable Lunar Lander Solar Array Systems: Requirements definition and concept evaluation leading to a 10kW-class solar array
  - Chemical Heat Integrated Power Source: Develop 100 W-class, 350 hour non-nuclear lunar night power source
- Energy Storage
  - Develop a sub-kW class, integrated Regenerative Fuel Cell (RFC) and conduct lunar relevant ground testing to demonstrate long-duration energy storage & night power generation (~350 hr)
  - Primary Fuel Cell Technology Tipping Point (Blue Origin, September 2019): Demonstrate fuel cell element on early lander using propellant-grade hydrogen and oxygen reactants to extend the lander surface mission duration
- Initiated for surface-to-surface power beaming, advanced rover energy storage technology and power distribution architectures.
- Conducting a phased, system level assessment of power architecture for lunar surface missions with HEOMD









Regenerative Fuel Cell (RFC) Overview

Objective

- RFC delivers an enabling technology suite that provides sustained and reliable electrical power for surface and near surface missions where PV/battery or Nuclear options are not feasible

Current Status

- Developing Conceptual System design for System Requirements Review / System Definition Review (SRR / SDR) in November 2019
- Developing specifications and Statements of Work for procuring fuel cell stack and electrolysis stack
- Identifying technology areas requiring further development and coordinating SBIR/STTR activities (e.g., product water management improvement). Scarring potential on-ramps for successful development

Deliverables/Schedule

- FY20: SRR / SDR; Award component hardware contracts; Preliminary Design Review
- FY21: Critical Design Review
- FY22: Assembled 100 W-class RFC ground demo unit; Lab Test Readiness Review (TRR); Thermal / Vacuum TRR
- FY22: Decision Point to determine Lunar Surface Fuel Cell Demos targeted for FY 23 and FY 25

Cold Operable Lunar Deployable Arm (COLDArm)

Objective
Significantly improve utility for lunar landers by providing manipulation capabilities through the lunar night. The arm will measure geotechnical properties to inform future technology development and missions

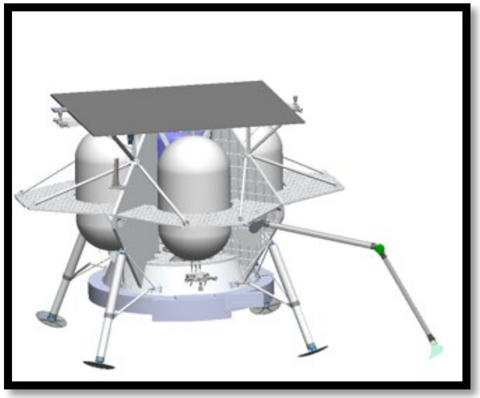
Description
The COLDArm system will include previously developed technologies, including bulk metallic glass (BMG) gears, cold motor drivers, and a 6-axis force torque sensor. COLDARM will expand the science capabilities for lunar robotic missions, including deploying instruments/payloads and sampling

Industry Partners
Motiv will provide the robotic manipulator and cold distributed motor. ATI will provide the 6-axis force torque sensor

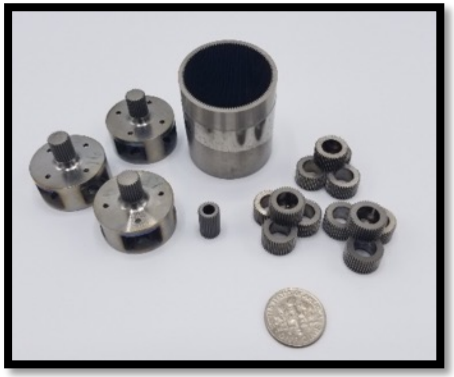
Infusion
Astrobotic has been identified and confirmed as a potential launch provider, both for initial Peregrine lunar lander, but also future Griffin lunar lander

Current Status
- FY 2020: Preliminary Design Review and Critical Design Review

Deliverables/Schedule
- FY 2022: COLDArm Hardware Functional Testing
- FY 2022: Integrated system demonstration
- FY 2022: COLDArm system environmental testing



(COLDArm CAD)



(BMG components in BMG 3-stage planetary gearbox assembly)

Delivery of COLDArm for potential CLPS mission in 2023

LSII Collaborative Approach

A key tenet of LSII is to implement a multitude of novel collaborations across industry, academia, and government in order to successfully develop the transformative capabilities for lunar surface exploration.

LSII leverages the broad range of STMD Programs in order to identify and establish meaningful collaborations. Some example of activities currently underway include:

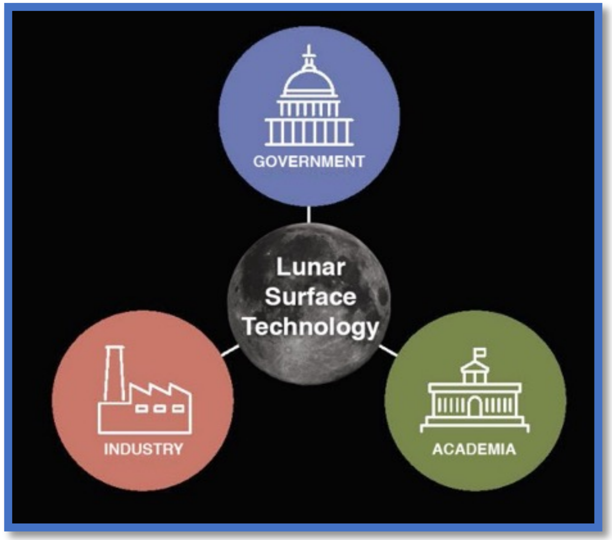
- LSII is one of the key focus areas for the Tipping Point and ACO solicitations released on 1/29/20; Multiple LSII related activities selected in previous calls (ACO, TP, etc).
- First SBIR Sequentials call is being prepared for larger small business awards ($5M)
- Initial APL system integrator task executed (Lunar Regolith Simulant Supply Chain Assessment w/JSC; Surface Power Assessment at GRC with multi-Centers)
- NextSTEP ISRU BAA's, including component and subsystem testing in simulated space environments
- Seven NASA Early Career Initiatives with LSII related content started in early FY20
- NIAC Phase 3 awarded for lunar technology enabling exploration of lunar pits
- Centennial Challenges Program is formulating LSII-related challenges, including Surface Power and Excavation.
- Two crowdsourcing challenges under development through NASA Tournament Labs including a call for payload designs for the PUFFER lunar scout and an open-source design challenge for the Regolith Advanced Surface Systems Operations Robot (RASSOR).

Lunar Surface Innovation
CONSORTIUM

The University Affiliated Research Center, Johns Hopkins Applied Physics Lab, has a task with NASA STMD to assess and recommend a model for a LSII technology system integration role. As part of this assessment, APL will convene the Lunar Surface Innovation Consortium composed of industry, academia and NASA with expertise in key lunar surface technology development capability areas.

Key Consortium Tenets

- **Technology** – Develop key lunar infrastructure capabilities
- **Collaboration** – Enable partnerships that leverage common objectives for establishing lunar infrastructure
- **Communication** – Create information paths to best match needs with opportunities
- **Future Workforce** – Ensure the the U.S. maintains the workforce needed for sustained space exploration



The Consortium Will…

- Identify lunar surface technology needs and assess the readiness of relative systems and components
- Make recommendations for a cohesive, executable strategy for development and deployment of the technologies required for successful lunar surface exploration
- Provide a central resource for gathering information, analytical integration of lunar surface technology demonstration interfaces, and sharing of results

Kickoff on 2/28/20 at APL with broad industry, academia, and government participation.

Small Spacecraft Technology Program

Objectives:

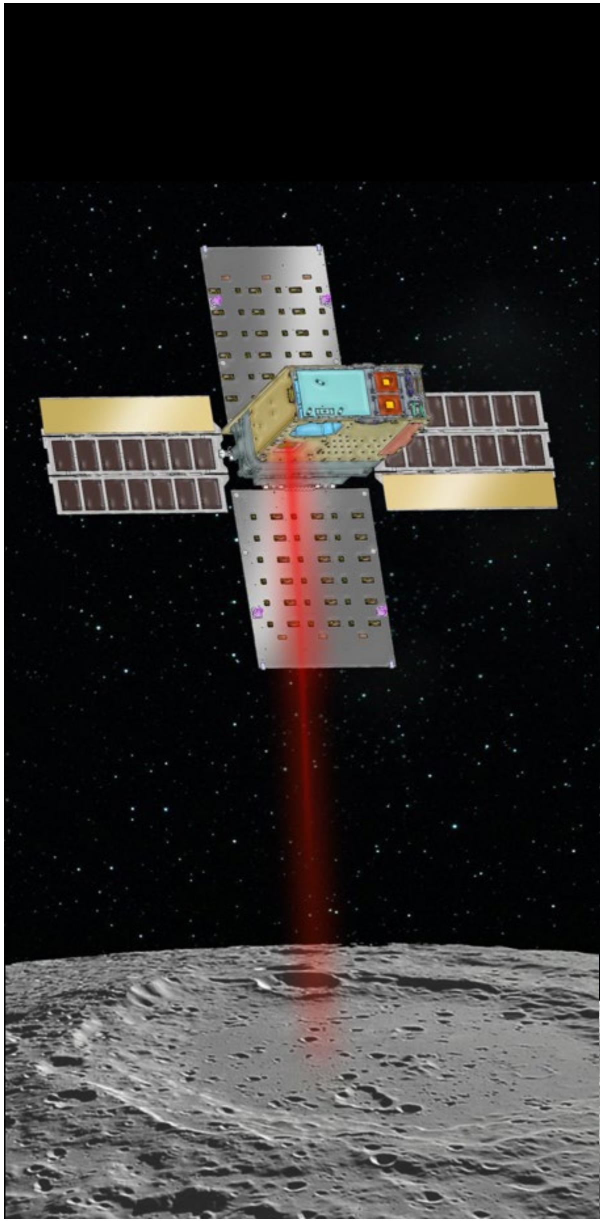
- Enable execution of missions at much lower cost than previously possible
- Substantially reduce time required for development of spacecraft
- Enable and demonstrate new mission architectures
- Expand the capability of small spacecraft to execute missions at new destinations and in challenging new environments
- Enable the augmentation of existing assets and future missions with supporting small spacecraft

Current Status:

- 19 Spacecraft currently in development across 15 missions, including two missions to the moon in 2021
- Engaged in 8 technology partnerships with academia and testing of multiple new technologies from industry

Deliverables/Schedule

- FY20: Launch of PTD-1 and PTD-2. Design/Integration reviews on 9 additional missions. Selection of 9 new technology partnerships
- FY21: Launch of CAPSTONE. Anticipated delivery of Lunar Flashlight, CLICK-A, PTD-3 and ACS3 for launch
- FY22: Anticipated delivery of CLICK-B/C and PTD-4 for launch



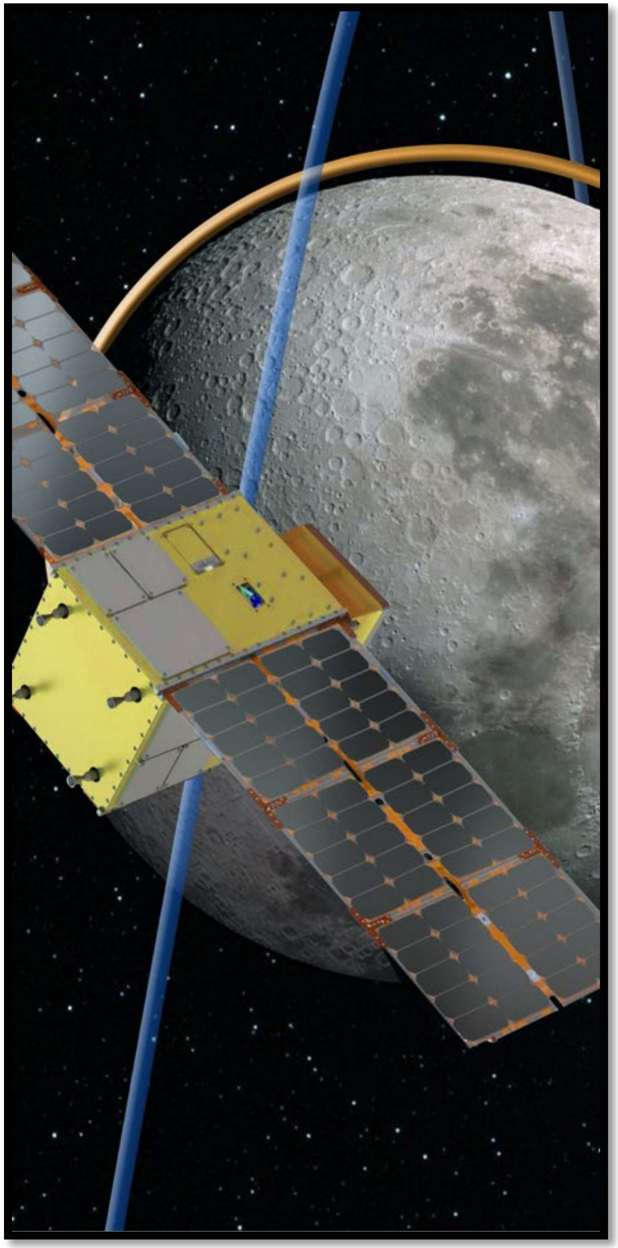
Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE)

CAPSTONE has contracts with Advanced Space LLC, Tyvak Nano-Satellite Systems Inc. and rapid commercial launch procured by HEOMD/AES

Objectives:
- Rapid demonstration leveraging American small businesses to test autonomous relative navigation for Gateway and other lunar missions, verify NRHO orbital dynamics, and demonstrate novel low energy transfers to cislunar space.
- Execute a cislunar mission in under $30M (including launch) and in under 3 years

Current Status:
- Kick off of SBIR Phase III award in September 2019.
- System Requirements Review and Preliminary Design Review completed in FY20

Deliverables/Schedule:
- FY20: Critical Design Review and Flight Hardware delivery
- FY21: Launch, lunar transfer, and begin demonstration operation in cislunar space
- FY22: Complete demonstration mission



Flight Opportunities Program

Objective:
Facilitate rapid demonstration of technologies for space exploration and expansion of space commerce through suborbital flight testing with industry partners.

In FY2019
- **47 payloads flown**
- **15 successful flights**
- **9 commercial flight providers active**
- **25 technologies selected via Tech Flights 2019 solicitation**

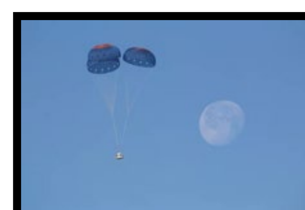
> - ***184*** Flights facilitated by Flight Opportunities (FO) through **the end of FY2019**
> - **A total of 651** payloads flown as of the end of FY2019 through FO

Highlights of recent milestone in the Flight Opportunities program:
- On **Dec. 6, 2019, 8** FO-supported payloads were tested aboard Blue Origin's New Shepard, including an experiment to study the impact of gravity transitions on gene expression and a system to manage trash and waste in space
- On **Nov. 21, 2019, 6** tests were performed abroad UP Aerospace's SpaceLoft rocket, with a focus on testing guidance and control systems and other system to enable small launch capabilities
- On **Sep 11, 2019** testing of a terrain relative navigation system was tested on Masten Space Systems Xodiac rocket, demonstrating critical landing capabilities for the Moon and Mars
- **On January 2020,** Draft of Tech Flights 2020 solicitation released allowing human tended payloads and adding dedicated funding for educational opportunities.

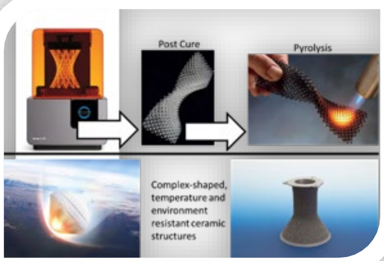
FY20-21: Award of suborbital opportunities to industry and academia. Integration of commercial suborbital testing opportunities into Small Spacecraft Technology and other NASA solicitations.

Commercial Flight Providers

Blue Origin · Masten · Zero G · Exos Aerospace · Virgin · World View · UP Aerospace · NSC · Raven



Early Stage Innovation Portfolio



- **NASA Innovative Advanced Concepts (NIAC):**
Push the boundaries of what is currently possible, engaging visionary innovators to explore radical concepts and redefine the future of aerospace

- **Space Technology Research Grants (STRG):**
Examine the feasibility of critical ideas while inspiring, training, and leveraging the academic community, from graduate students to senior faculty

  Space Technology Research Institutes (STRI): Advance scientific and technological areas key to NASA's future through sustained, coordinated investment in multi-disciplinary, university-led research

- **Center Innovation Fund (CIF):**
Seed technology to transform future missions by stimulating innovation at all NASA Centers and partnering with researchers across the Nation

- **Early Career Initiative (ECI):**
Invigorate NASA's technological base and management practices by partnering early career NASA leaders with world-class external innovators

Focusing Early Stage Innovation Portfolio investments to enable and mature technologies for Moon to Mars

Early Career Initiative (under the CIF Program)

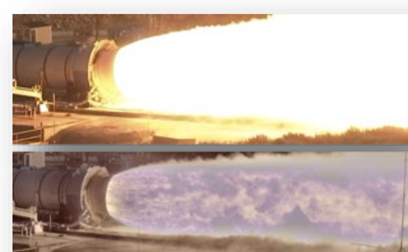
Initiative Goal
Invigorate NASA's technological base and best practices by partnering early career NASA leaders with world class external innovators.

- NASA needs top-notch employees to fill gaps that are growing as people retire.
  - **Initiative to accelerate some early career Civil Servants' capabilities with in an exciting and challenging fashion.**
- STMD is looking for effective management approaches for technology development projects.
  - **Initiative requires alternative management approach (not NPR 7120-based)**
- NASA should work with appropriate partners when possible, to gain access to knowledge, technology, and/or expertise.
  - **Initiative requires partnering with a non-NASA entity (University, other government Agency, business, non-profit).**

Solicitations every year; 2 year projects that start on October 1; $2.5M maximum budget

MSFC LISA-T (Lightweight Integrated Solar Array and Transceiver) self-unfolding system worked well. Investigating flight system for cubesat. Flying various elements on MISSE 10.

KSC IDEAS (Integrated Display and Environmental Awareness System) is continuing development with GSDO funds; still partnered with small business. Collaborating with JSC.



SSC HiDyRS-X (High Dynamic Range Stereo-X) is advancing with other funds and commercial partnerships. Currently working to integrate it onto a single mask/imager system.

Patterned Magnetic Hold-Separate Techniques

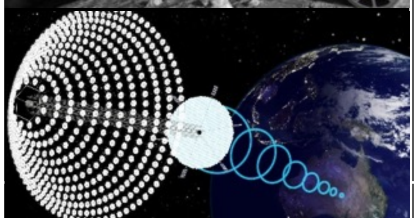
ECI Portfolio: FY 2018-2020

ECI Title	Center	Partner	Year
Autonomous Guidance and Control System for Deployable Entry Vehicles	ARC	UC Davis, Johns Hopkins University Applied Physics Laboratory	2
Orbital Syngas/Commodity Augmentation Reactor	KSC	Blue Origin	2
Electro-Optical Technology Development In Liquid Crystal Beam Steering	LaRC	Boulder Nonlinear Systems	1
Smart Habitat Robotics: Manipulation Technology to Enable Autonomous Uncrewed Habitats	JSC	Woodside Energy	1
Autonomous Multifunctional Sensor Platform	GSFC	Northeastern University	1
FY 2020			
Development of a Thermal Control System to Survive the Lunar Night	MSFC	Astrobotic	0
In-Space Assembly of Perovskite Solar Cells for Very Large Arrays: Space power at terrestrial costs	GRC	University of California Merced, National Renewable Energy Lab (NREL)	0
Molten Regolith Electrolysis – Starter Device	KSC	Honeybee Robotics	0
Joint Augmented Reality Visual Informatics System: xEMU Spacesuit Heads-In Display Visual Aid to Enable Crew EVA Autonomy	JSC	Collins Aerospace	0
Extractor for Chemical Analysis of Lipid Biomarkers in Regolith	ARC	Shell Global Solutions	0
A Mobile Frequency-Modulated Continuous-Wave Light Detection and Radar System for Lunar Surface Terrain-Mapping and Navigation	MSFC	Torch Technologies	0
Assemblers: A modular and reconfigurable manipulation system for autonomous in-space assembly	LaRC	Honeybee Robotics, Virginia Tech	0

NASA Innovative Advanced Concepts

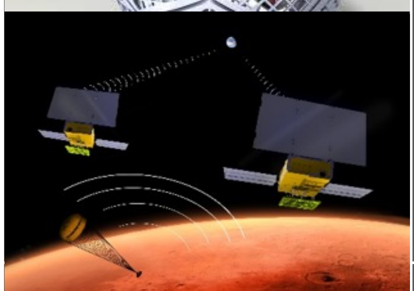
Current and Future Milestones:

Phase III studies added to advance two NIAC Technologies from low to mid-TRL.



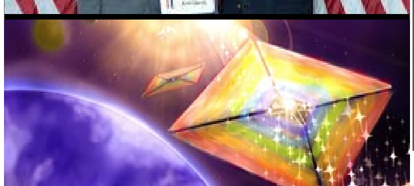
The U.S. Air Force Research Lab began a $100M program to develop hardware for a solar power satellite based on John Mankins' study.

Ali Aghamohommadi- In 2021 Shapeshifter will deploy on the DARPA Challenge in partnership with Stanford, Cornell University.



MarCO Mission: The first interplanetary CubeSats were recognized by the engineering community with the ***2019 Small Satellite Mission of the Year Award****, provided real-time communications link to Earth for InSight during its entry, descent, and landing (EDL) on Mars. First image of Mars from a CubeSat.*

Presidential Early Career Award for Scientists and Engineers (PECASE) *awarded to Jonathan Sauder for demonstrating innovative technologies to enable a new class of space missions.*



Beam Rider: The "beam-rider" technology could guide light sails and probes to faraway stars or to closer targets in our own Solar System instead of chemically powered rockets.

Objectives:

- Advance NIAC Technologies from low to mid-TRL
- Develop follow-on paths for current studies and assess for NASA missions
- Attract and engage new and diverse researchers to NASA
- Support early-stage advanced spin off technologies and new businesses to build the U.S. economy

Deliverables/Schedule:

FY19: Fund 12 Phase I Fellows, 6 Ph II Fellows, 2 Ph III Fellows

FY20: Fund 15 Phase I Fellows, 7 Ph II Fellows, 1 Ph III Fellow

FY21: Fund 15 Phase I Fellows, 7 Ph II Fellows, 1 Ph III Fellow

PPBE 2021 proposed Funding increase will enable additional Phase III awards and/or increased award value

Additional Milestones:

- Mel Ulmer (IL)- magnetic smart materials to build large in-space telescope received $450K add-on funding from another government agency
- Stephanie Thomas (NJ)- fusion energy study, $1.25M ARPA-E award, two patent applications and an invention for magnetic dipole cancellation, and direct conversion of thermal energy to DC power
- John Slough/David Kirtley (WA)- $20M VC investment, $8M DoE ARPA-E, start-up Helion Energy, fusion as potential commercial energy source, 30 employees
- John Kendra (VA)- new patent application from Leidos based on NIAC R-MAX study
- Sercel (CA) started a business from NIAC study (TransAstra) Slough- $20M VC investment, $8M DOE ARPA-E, 30 full time employees

Space Technology Research Grants Program

Awards: 710 States: 43 Territories: 1 *(PR)* Universities: 112

Engage Academia

Tap into spectrum of academic researchers, from graduate students to senior faculty members, to examine the theoretical feasibility of ideas and approaches that are critical to making science, space travel, and exploration more effective, affordable, and sustainable

- **NASA Space Technology Graduate Research Opportunities (NSTGRO)**
- **Early Career Faculty (ECF)**
- **Early Stage Innovations (ESI)**
- **Space Technology Research Institutes (STRI)**

88 new awards in FY20

ESI: 14 NSTGRO: 65 ECF: 9 (selected)

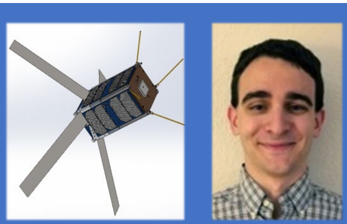
✓ **2 STRI18 grants** awarded

✓ ***300+ active awards***

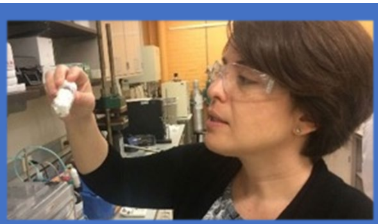
✓ ***165+ graduate researcher visits to NASA Centers***

Accelerate development of ground-breaking high-risk/high-payoff low-TRL space technologies

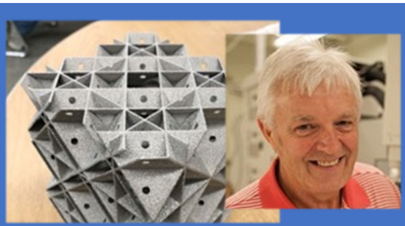
Over 40% of completed STRG grants receive follow-on funding from other sources to directly use or further develop their technologies



NSTRF17 Sanny Omar/University of Florida - Built a new type of cubesat drag device to safely deorbit these satellites and minimize space junk. His invention will fly this year.



ECF18 - Burcu Gurkan/Case Western Reserve University – Named 2019 influential researcher by the I&EC Journal for her work on ionic liquid based CO_2 scrubber technology.



ESI17 - Haydn Wadley/University of Virginia - Created new structural lattice materials with double the strength of currently used honeycomb sandwich structures.

CUBES

STRI16 - CUBES – The institutes Food and Pharmaceutical Synthesis Division has already grown and extracted a bone regeneration therapeutic compound from lettuce plants and is working on synthesizing other medicines.

Space Technology Research Institutes (STRI) 2016

The goal of the Space Technology Research Institutes (STRI) is to strengthen NASA's ties to the academic community through long-term, sustained investment in research and technology development critical to NASA's future

Computationally Accelerated Materials Development for Ultra High Strength Lightweight Structures

- Institute Title: The Institute for Ultra-Strong Composites by Computational Design (US-COMP)
- Lead Organization: Michigan Technological University
- Partner Organizations: University of Utah, Florida A&M University; University of Minnesota, John Hopkins University, MIT, Georgia Tech, University of Florida, Nanocomp Technologies Inc., AFRL, Virginia Commonwealth University, Solvay
- US-COMP will serve as a focal point for partnerships to:
  - Enable computationally-driven development of carbon nanotube based ultra high strength lightweight structural materials within the Materials Genome Initiative (MGI)
  - Expand the resource of highly skilled engineers, scientists and technologists in this emerging field.

US COMP

Bio-Manufacturing for Deep Space Exploration

- Institute Title: The Center for the Utilization of Biological Engineering in Space (CUBES)
- Lead Organization: University of California, Berkeley
- Partner Organizations: University of Florida, Utah State University, University of California, Davis, Standford University, Autodesk
- CUBES will leverage partnerships to:
- Support biomanufacturing for deep space exploration
- Advance the practicality of an integrated, multi-function, multi-organism biomanufacturing system on a Mars mission
- Showcase a continuous and semiautonomous biomanufacturing of fuel, materials, pharmaceuticals, and food in Mars-like conditions

CUBES

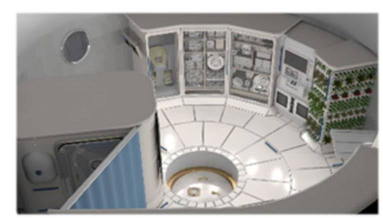
Space Technology Research Institutes (STRI) 2018

Smart Deep Space Habitats (SmartHabs)

- Two institutes funded under this topic in September 2019
- kickoff meetings held with strong NASA participation

- Institute Title: Resilient ExtraTerrestrial Habitats research institute (RETHi)
- Lead Organization: Purdue University
- Partner Organizations: University of Connecticut, Harvard College, University of Texas at San Antonio, ILC Dover, Collins Aerospace
- RETHi seeks to design and operate resilient deep space habitats that can operate in both crewed and uncrewed configurations.
    - The institute plans to leverage expertise in civil infrastructure with advanced technology fields such as modular and autonomous robotics and hybrid simulation and
    - Plans to create a cyber-physical prototype testbed of physical and virtual models to develop, deploy and validate different capabilities.

- Institute Title: Habitats Optimized for Missions of Exploration (HOME)
- Lead Organization: University of California, Davis
- Partner Organizations: University of Colorado, Boulder; Georgia Tech Applied Research Corporation; Carnegie Mellon University; Howard University; Texas A&M Engineering Experiment Station; University of Southern California; Blue Origin, LLC; Hamilton Sundstrand Space Systems International Inc
- The HOME institute seeks to enable resilient, autonomous and self-maintained habitats for human explorers through the advancement of early-stage technologies related to autonomous systems, human and automation teaming, data science, machine learning, robotic maintenance and onboard manufacturing.



Center Innovation Fund

CIF stimulates and encourages creativity and innovation from within the NASA Centers to transform NASA missions and advance the Nation's capabilities. There is a new slate of projects each year.

- Solicitations at all 10 Centers are run by each Center Chief Technologist with final selection/approval made by STMD.
- **127 FY 2019** CIF projects at all 10 Centers covering **all 15 Technology Areas.**
- FY 2021 projects will be announced in late September and encourage alignment to key capabilities to enable a sustainable Lunar presence and human missions to Mars

FY 2020 Highlighted Projects:

- Lunar Autonomous Position System – for autonomous navigation on and around the moon;
- Enabling Exploration of Permanently Shadowed Craters using RF power/comm;
- Novelty-Driven Onboard Targeting for MSL and Mars 2020 Rovers to aid exploration;
- Onboard Autonomous Trajectory Planner-supports off-nominal safe operations;
- 3D Printed Cryogenic Strut – improves cryogenic fluid capabilities

Electrodynamic Dust Shield Coating Pattern for Solar Cells

Electrodynamic dust shield before and after (left and right respectively) clearing JSC-1A lunar dust simulant in a vacuum.

PRIZES AND CHALLENGES: Centennial Challenges

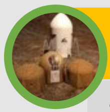
Since 2005, Centennial Challenges has incentivized the public to develop innovative solutions to NASA technology gaps. Former teams currently working with NASA include: Masten Space Systems, Ragnarok Industries, and Final Frontier.

307 Teams

From **42** States

$10M Awarded

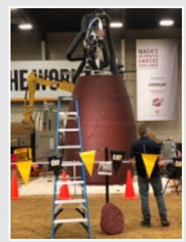
RECENT HIGHLIGHTED SUCCESSES



3D-Printed Habitat Challenge (Completed)

State-of-the-art in autonomous vertical 3D printing construction technology for space and Earth.

- Completed May 2019; $2.06M awarded
- Over $10M in investments from commercial entities.
- Sparked commercialization of technology for Earth applications including affordable housing solutions.



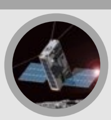
CO_2 Conversion Challenge (Active)

Convert CO_2 into sugar molecules that can be used to produce mission critical supplies.

- Awarded $250K in Phase 1; $750K purse for Phase 2 (in progress).
- Solutions from this competition could create game-changing technologies for life support for the Moon and Mars.
- Create potential on-demand bio-farms to provide medicines, food and building materials.

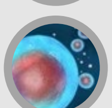
FY2020–2021 PLANS

ADDITIONAL ACTIVE CHALLENGES



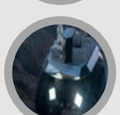
Cube Quest $5M

CubeSats to be launched on Artemis I, advancing deep space propulsion and communications. $460K awarded to date.



Vascular Tissue $500K

Printing viable thick organ tissue that can advance research and medicine in space and on Earth.



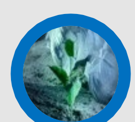
Space Robotics $1.9M

Advancing robotic software and autonomous capabilities. $570K awarded in phase 1; $1M purse for Phase 2 (in progress)

IN DEVELOPMENT

Lunar Power $5M

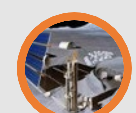
Energy storage and distribution for future Moon missions.



Lunar Nutrition $3M

Improve access to fresh, healthy and tasty food for long duration missions.

IN FORMULATION



Lunar Excavation, Manufacturing & Construction $5M

Game-changing autonomous operations targeting a large scale, end-to-end demonstration.

PRIZES AND CHALLENGES: NASA Tournament Lab

Since 2011, the NASA Tournament Lab has enabled NASA researchers, scientists, and engineers to conduct public and internal challenges and other crowdsourcing projects to acquire novel ideas or solutions to accelerate R&D efforts in support of the NASA mission.

344
NASA crowdsourcing projects launched

72M
People accessed worldwide thru 17 crowdsourcing communities

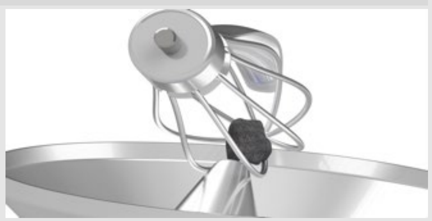
$18M
Savings estimated v. using traditional innovation methods

RECENT HIGHLIGHTED SUCCESSES

Sample Return Regolith Sorter Challenge

5 innovative designs were selected from 200+ submissions as starting point for lunar sample mission designs.

A challenge to design a sampling system for acquiring a defined amount of regolith within specific size ranges while operating under the lunar environmental constraints.



NASA Earth & Space Air Prize

Accurate and affordable aerosol sensor

Public/private partnership with Robert Wood Johnson Foundation to advance the state of the art on aerosol sensors needed for spacecraft and cities on Earth.

FY2020–2021 PLANS

Complete 31 NASA challenges currently in progress

Develop and execute 25+ candidate challenges including:
Exploring Hell: Venus Rover Obstacle Avoidance, Mini-Payloads for Small Lunar Rovers, Artemis Camera, Gateway Frozen Sample, EVA Parametric Mass Modeling, Drone AR Visualization, Food Safety Imaging, Advance Thermal Coatings, OCT Seedling

Develop & launch at least $400K in challenges resulting from NASA's "Crowdsourcing Contenders" solicitation

Award the NOIS2 (NASA Open Innovation Services 2) multi-vendor crowdsourcing contract
Supporting a pilot for internally finding needed skills
(Part of Agency Digital Transformation)

Facilitate challenges for other agencies including DHS, NIST, USBR, NGA, CDC, USDA, USAID, DIA, FAA, NOAA, NIH, IARPA (11 challenges in progress)

Technology Transfer Program

Finding NASA technology is easy through our online portal, technology.nasa.gov. Licensing fast and straightforward through an online application system. We also offer programs for emerging entrepreneurs like Startup NASA and a university program, T2U (Tech Transfer University).

NASA's software inventory is available—without cost—to industry, academia and other government agencies on software.nasa.gov, the Federal Government's first and only comprehensive software inventory.

Our commercialization success stories are published annually in our Spinoff report and online at spinoff.nasa.gov.

Public-Private Partnerships: Announcement of Collaborative Opportunity

- **Advance Emerging Space Technology System Capabilities (Minimum TRL 3)**
- Partnerships focused on industry-developed space technologies that can advance the commercial space sector and benefit future NASA missions
- Can accelerate the availability of, and reduce costs for the development and infusion of these emerging space system capabilities
- NASA will provide technical expertise and test facilities, as well as hardware and software to aid industry partners
- OTA Award value of in-kind resources worth about $1M over 1-2 year period

- 2020 Announcement released on Jan 29, 2020 (https://go.usa.gov/xdx85)
- Topics:

Cryogenic Fluid Management & Propulsion	*Sustainable Power*
Advanced Propulsion	*In-situ Propellant/Consumable Production*
Entry, Descent and Landing	*Intelligent/Resilient Systems & Advanced Robotics*
Operate in Extreme Environments	*Advanced Materials and Structures*
Extreme Access	*Small Spacecraft Technologies*

NASA anticipates releasing ACO every year https://go.usa.gov/xQRwV

Public-Private Partnerships: Tipping Point Technologies

- **Advance Tipping Point Space Technology System Capabilities (Minimum TRL 4)**

- *Tipping Point Definition: An investment in a ground/flight demo will result in:*
  - *a significant advancement of the technology's maturation, and*
  - *a significant improvement in the offerors' ability to successfully bring the technology to market*
  - *Substantial benefit to **both** commercial and government sectors*

- Increased Focus on Collaboration with the commercial space sector
- Leverage emerging markets and capabilities to meet NASA's strategic goals & focus on industry needs
- Increase likelihood of infusion into a commercial space application & NASA mission
- Requires a minimum **25 percent contribution** (**10% for small businesses**) from industry

- 2020 Solicitation released on Jan 29, 2020 (https://go.usa.gov/xdx8k)
- Topics (Multiple Flight Demonstration Awards totaling $250M):
  - *Cryogenic Fluid Management Technology Demonstration*
  - *Lunar Surface Innovation Initiative Technology Demonstration in the areas Sustainable Surface Power, Extreme Environments, Extreme Access, Dust Mitigation, In-situ Resource Utilization, and Surface Excavation and Construction*
  - *Closed-Loop Descent and Landing Capability Demonstration, Validation of Modeling Tools with Lunar-Relevant Flight/Test Data*

NASA anticipates releasing TP Solicitation every year https://go.usa.gov/xQRwV

Tipping Point Technologies
Past Awards

- **Tipping Point Technology Topics – 2016 (9 awards/$71M)**
  - Robotic In-Space Manufacturing and Assembly of Spacecraft/Space Structures (3 awards)
  - Low Size, Weight and Power Instruments for Remote Sensing Applications (2 awards)
  - Small Spacecraft Attitude Determination and Control Sensors and Actuators (2 awards)
  - Small Spacecraft Propulsion Systems (2 awards)

- **Tipping Point Technology Topics – 2017 (6 awards/$12M)**
  - Small Launch Vehicle Technology Development (6 awards)

- **Tipping Point Technology Topics – 2018 (6 awards/$21M)**
  - ST1: Expand Utilization of Space (1 award)
  - ST2: Enable Efficient and Safe Transportation Into and Through Space (3 awards)
  - ST3: Increase Access to Planetary Surfaces (2 awards)

- **Tipping Point Technology Topics – 2019 (14 awards/$43M)**
  - Advanced Avionics (2 awards)
  - Autonomous Operations (1 award)
  - Cryogenic Propellant Production and Management (4 awards)
  - Efficient and Affordable Propulsion Systems (3 awards)
  - Rover Mobility (1 award)
  - Sustainable Energy Generation, Storage and Distribution (3 awards)

Announcement of Collaborative Opportunity
Past Awards

- **2015 Technology Topics – (13 awards)**
  - Suborbital Reusable and Small Satellite Launch Systems Development (4 awards)
  - Thermal Protection System Materials and Systems Development (3 awards)
  - Green Propellant Thruster Technology Qualification (3 awards)
  - Small, Affordable, High Performance Liquid Rocket Engine Development (3 awards)

- **2017 Technology Topics – (10 awards)**
  - Small Launch Vehicle Technology Development (3 awards)
  - Reliable Electronics Technology Development (3 awards)
  - Advanced Communications Technology Development (2 awards)
  - In-space Propulsion Technology Development (2 awards)

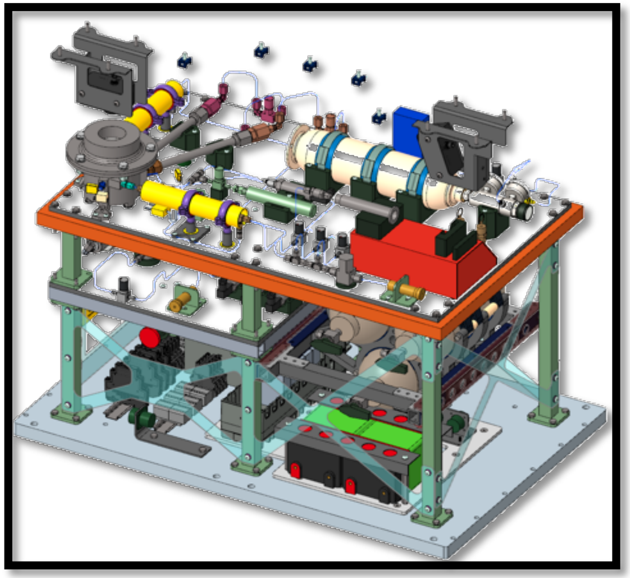
- **2019 Technology Topics – (19 awards)**
  - Advanced Communications, Navigation, and Avionics (2 awards)
  - Advanced Materials (2 awards)
  - Entry, Descent, and Landing (6 awards)
  - In-Space Manufacturing and On-Orbit Assembly (1 award)
  - Power (2 awards)
  - Propulsion (4 awards)
  - Other Space Technologies (2 awards)

Orbital Syngas/Commodity Augmentation Reactor (OSCAR) [KSC]

- OSCAR is an experiment designed to take waste materials and burn it in a reactor to break it down into chemical sub-components that can be reused. Recycling is critical for long-term habitation in space.

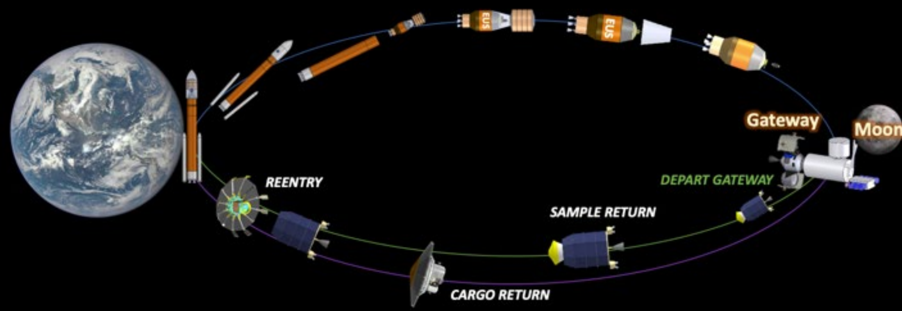
- OSCAR flew on a Blue Origin sounding rocket in December and successfully demonstrated zero-gravity trash to gas conversion. Blue Origin was the primary partner on this work, providing engineering and specification services as well as the New Shepherd sounding rocket.

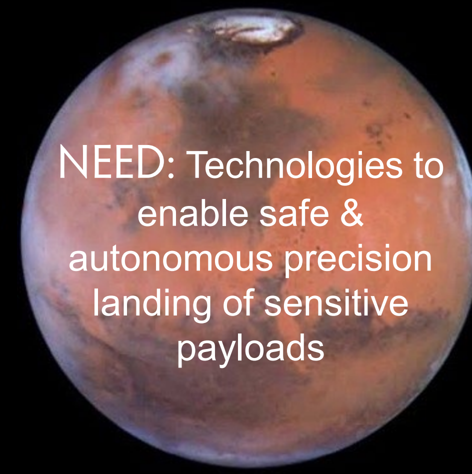
- Video data shows the burn process, while the gas products were captured for later analysis. This data is being compared with 2 second and 5 second drop test results as well as tests in full gravity. HEOMD AES (Advanced Exploration Systems) is funding further work in this area.



Pterodactyl: Precision Targeting of Deployable Entry Vehicles [ARC]

Imagine delivering payloads to planetary bodies with the <u>ease</u> you send packages using UPS and at a <u>reduced cost</u> because you can deliver direct to your precise destination!



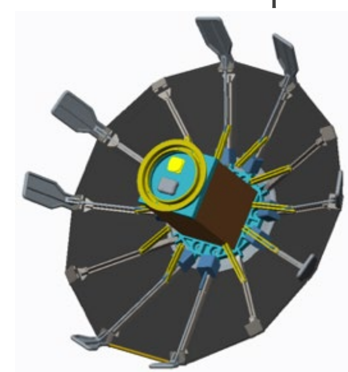


NEED: Technologies to enable safe & autonomous precision landing of sensitive payloads

SOLUTIONS

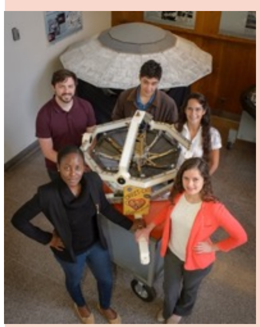
Using an integrated SW & HW design approach, Pterodactyl has developed multiple **innovative guidance & control systems** for precision targeting of deployable entry vehicles (DEVs) that increase maneuverability and maximize useable payload volume.

DEV with Flaps



The Team

NASA SILICON VALLEY
AMES RESEARCH CENTER



- ARC, Lead Center: Project Management, Mission Design, Control Systems Design, Aero/Aeroheating, Mechanical Design and Structures, Heatshield Design
- JSC: Guidance & Trajectory Design
- **JHU Applied Physics Laboratory: Flight Operations, Systems Engineering**
- UC Davis: Aerodynamics Research

Hybrid Project Management

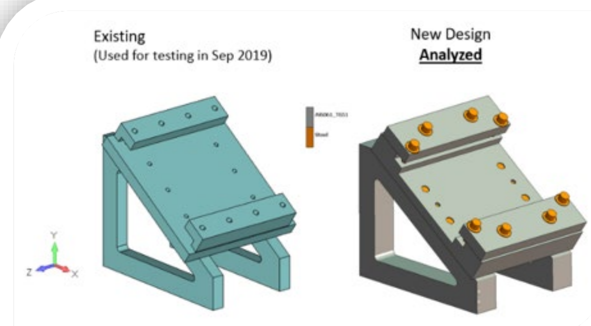
Leveraged agile and traditional approaches for parallel development of software and an integrated hardware prototype to deliver a feasible, innovative flap control system

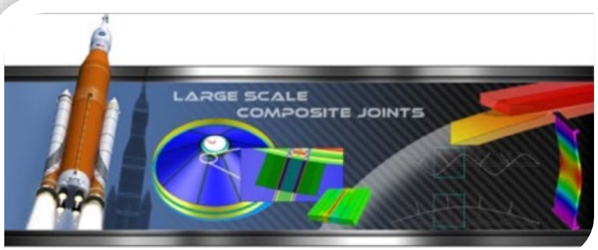
Technology Infusion Successes

Astrobee

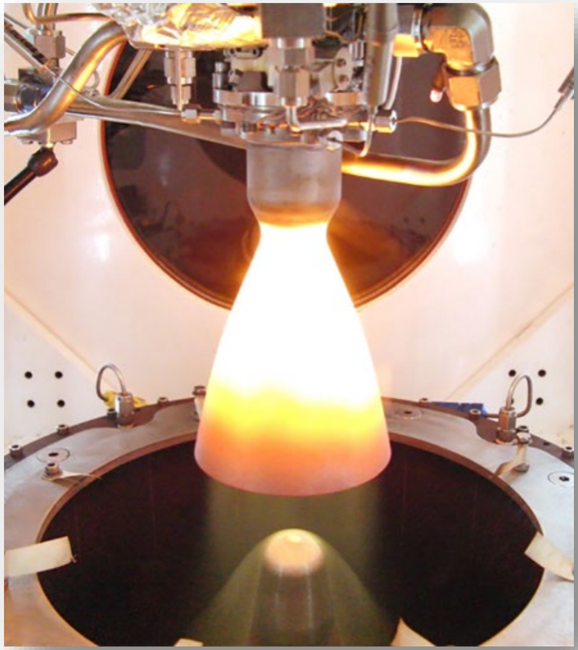
- Astrobee, NASA's next-generation free-flying robotic system on the ISS, will advance the agency's Artemis mission by saving valuable astronaut time and advancing autonomy research.
- Guest scientists will be able to use Astrobee to carry out investigations that will help to develop technology – both hardware and software – for future missions.
- Working autonomously or via remote control by astronauts, flight controllers or researchers, the robots will help complete tasks such as inventory and documenting experiments conducted by astronauts.

- **Composite Technologies for Exploration (CTE)**
- The CTE composite joints technology development benefits include mass and part reduction, which results in significant cost savings and increased payload capability for launch vehicles.
- CTE's longitudinal bonded joints have been baselined for the SLS Payload Adapter to reduce weight and manufacturing time, replacing traditional metallic methods.
- In addition, CTE's circumferential bonded joints will provide lighter weight structures for greater performance and increased payload capability for future SLS block upgrades.
- CTE will enable the technology infusion of lightweight composite joints into future exploration missions.





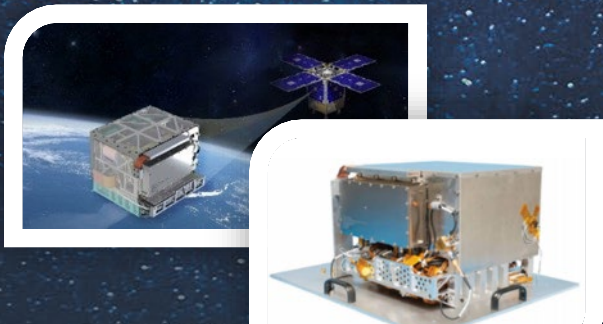
Technology Infusion Successes cont.



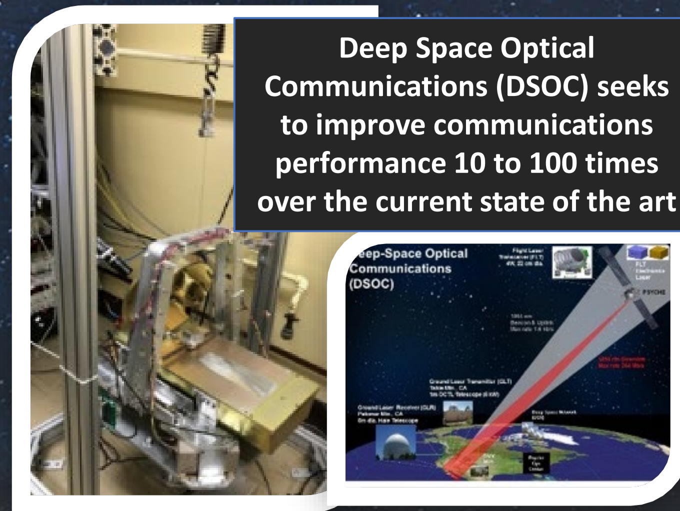
The Thruster for the Advancement of Low-temperature Operation in Space (TALOS)

- Frontier Aerospace Corporation (FAC) contract for the design and development of high-performance, lightweight, and compact spacecraft propulsion systems.
- Astrobotic's (of Pittsburgh, Pa.) Peregrine lander has baselined the TALOS thrusters for both axial and attitude control system propulsion for their lunar mission demonstration scheduled for 2021. Under the TALOS project, the thrusters will be flight qualified to approximately technology readiness level (TRL)-6.
- A Tipping Point contract has been awarded to FAC to provide the first flight set of axial thrusters for the Astrobotic mission. The flight of the Peregrine mission is expected to advance the TRL of the TALOS thruster to TRL-9.

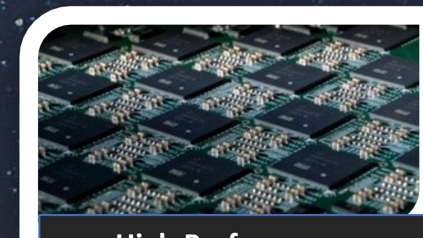
Exploration Technology in Deep Space Communications, Navigation and Advanced Avionics



Deep Space Atomic Clock (DSAC) is a revolutionary smaller space clock design, requires less power, and is more stable than current space-qualified atomic clocks

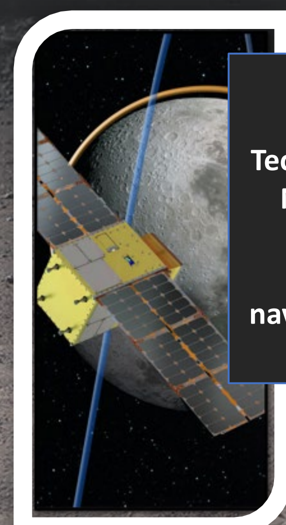


Deep Space Optical Communications (DSOC) seeks to improve communications performance 10 to 100 times over the current state of the art



High Performance Spaceflight Computing (HSPC) offers new advanced flight computing architecture

Laser Communications Relay Demonstration (LCRD) will be NASA's first end-to-end optical relay



Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) test autonomous relative navigation for Gateway and other lunar missions

CubeSat Laser Infared Crosslink (CLICK) mission that will demonstrate optical crosslink and timing exchange between two small spacecraft in LEO

Laser Communications Relay Demonstration

Objectives:

- Demonstrate bidirectional optical communications between geosynchronous Earth orbit (GEO) and Earth
- Measure and characterize system performance over a variety of conditions
- Develop operational procedures and assess applicability for future missions
- Transfer laser communications technology to industry for future missions
- Provide an on orbit capability for test and demonstration of standards for optical relay communications

Current Status:

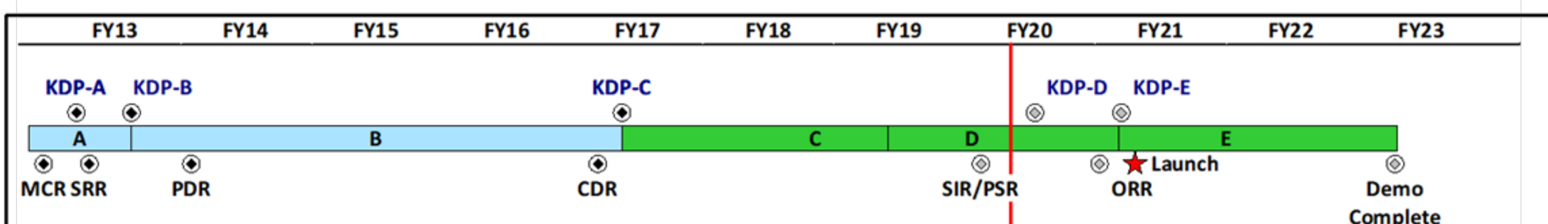
- The LCRD flight payload was delivered to Northrop Grumman January 22, 2020
- The LCRD team is supporting payload physical integration and testing of the LCRD payload with the STPSat-6 space vehicle
- Mission Readiness and Ground Readiness Testing will be performed with the integrated STPSat-6 space vehicle

Deliverables/Schedule

- FY20: Completion of environmental and performance testing
- FY20: Delivery to spacecraft provider and KDP-D.
- FY21: Launch and On Orbit Operations

A two year flight demo to revolutionize the way data is sent and received through space by advancing optical communications technology to assess its value for Deep Space and Near Earth operational systems

LCRD Flight Payload



Deep Space Optical Communications (DSOC)

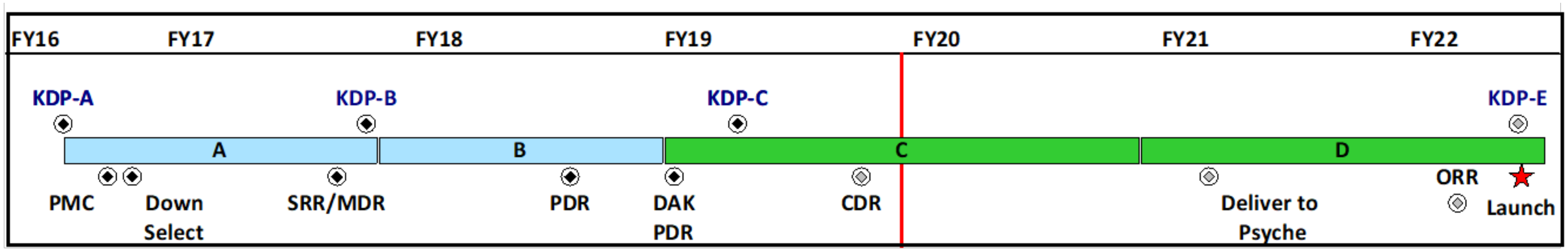
Objectives:
- Achieve 10 to 100 times greater data-rate performance from deep space with comparable mass and power to state-of-art radio frequency telecommunications systems
- Retire the implementation risks of utilizing optical communications technology on deep space missions

Current Status:
- Completed System Requirements Review, Mission Definition Review, KDP-B, Preliminary Design Review, KDP-C, Critical Design Review, and Ground Preliminary Design Review
- Fabrication of engineering models continues along with environmental qualification testing
- Started fabrication and assembly of Flight Units

Deliverables/Schedule
- FY19: PDR and KDP-C (complete)
- FY20: CDR (complete)
- FY21: Delivery to spacecraft
- FY22: KDP-E and Launch aboard Psyche
- FY23: DSOC demonstration complete

Fall 2022 Spaceflight demonstration of deep-space laser communications with orders of magnitude improved data rates (>200 Mbps) from Psyche satellite to Earth with mass and power comparable to state-of-the-art radio frequency telecommunications systems.

Artwork depicting spacecraft carrying DSOC orbiting Psyche



Deep Space Atomic Clock (DSAC)

Objectives:

- Demonstrate timekeeping stability suitable for deep space navigation in a space environment
- Maintain sustained operations in space for a year

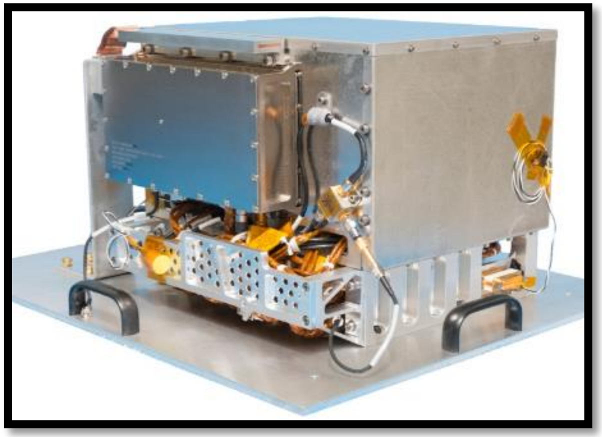
Current Status:

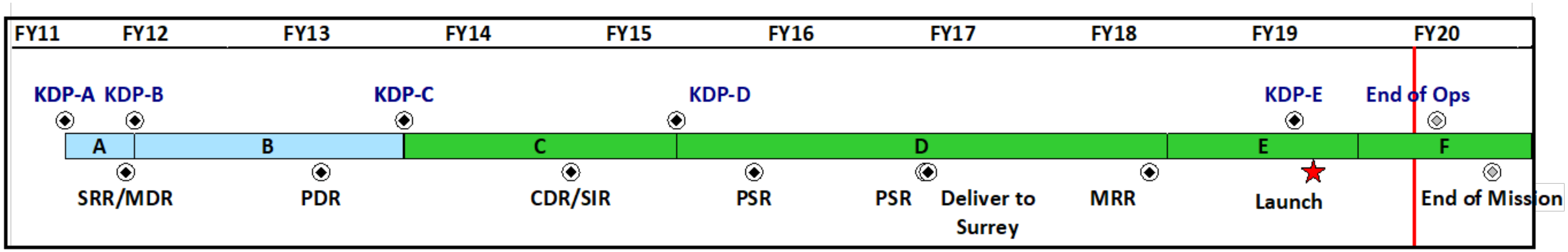
- Successful launch June 25 on Air Force STP-2 Falcon Heavy
- Clock operations began in August with subsystem and system level checkouts – first ever ion space clock has been operating nominally since
- Program level requirements satisfied for stability (gaining/losing < 2 nanoseconds per day) and deep space navigation utility (demonstrated orbit determination accuracies similar to a Mars orbiter)
- Clock controller improvements in work to push towards significantly better performance (goal of gain/loss < 0.3 nanoseconds per day)

Deliverables/Schedule

- Begin Operations 8/19/2019
- One year mission completion 8/19/2020

DSAC is the first timekeeper stable enough to map a spacecraft's trajectory in deep space while being small enough to fly onboard the spacecraft. This demonstration mission is a critical step toward enabling spacecraft navigation without relying on directions from earth.





High Performance Spaceflight Computing (HPSC) Overview

Objective

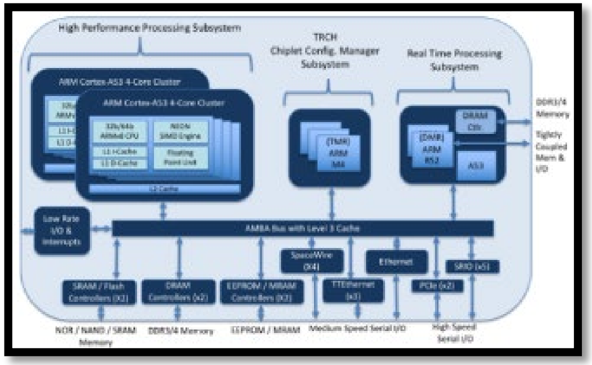
- HPSC offers a new flight computing architecture with the potential of 100X the computational capacity of current flight processors for the same amount of power, with provisions for extensibility and interoperability

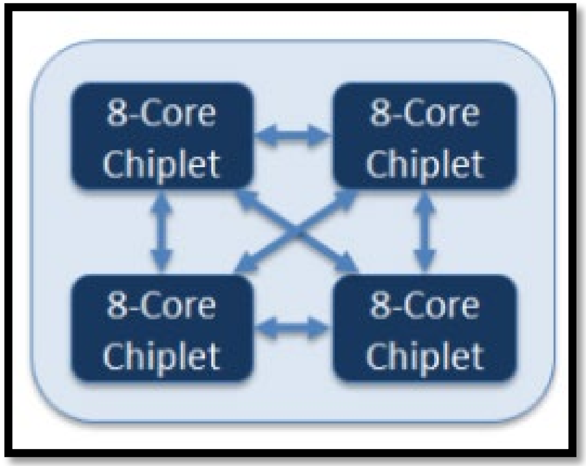
Current Status

- The original plan to manufacture the chip with a 32nm (circuitry line width) process was impacted by an earlier-than-anticipated commercial vendor decision to close the production line. This has resulted in a major chip design change, with Boeing assessing two alternate process options (22nm or 14 nm) to meet NASA requirements
- Project is in the process of generating higher-fidelity cost and schedule estimates for a 22nm HPSC chip that will be provided to NASA in March 2020 for further assessment

Deliverables/Schedule

- FY20 – Preliminary Design Review (PDR) for updated HPSC chip development
- FY21 – Implementation of a test chip for functional, radiation and system testing
- FY22 – Completion of first HPSC Spin-1 chip with testing initiated





Autonomous Pop Up Flat Folding Explorer Rover (A-PUFFER)

Objective

Demonstrate collaborative autonomous platform by navigating, communicating, computing, perceiving, and decision-making without human interaction for exploring extreme lunar and planetary terrains

Description

A-PUFFER is a low-mass, low-volume, low-cost autonomous rover for collaboratively exploring high-risk environments without endangering primary assets. The small rover is outfitted with collapsible wheels, motors, batteries, and radio, and accommodations to integrate a variety of small sensors

Current Status

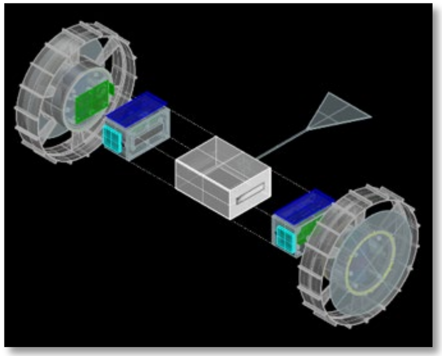
- March 2020: Multi-PUFFER field test
- May 2020: Multi-PUFFER field test incorporating results from first field test
- June 2020: Transition to Cooperative Autonomous Distributed Robotic Explorers (CADRE) project slated for CLPS mission

Deliverables/Schedule

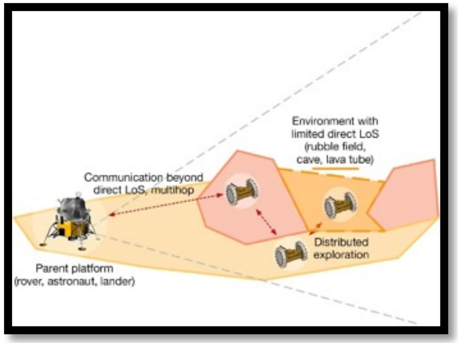
- FY 2021: CADRE Mission Design Review
- FY 2021: Autonomy testbed flight demonstration
- FY 2022: CADRE flight readiness review

Delivery of CADRE autonomous platforms for CLPS mission in 2023

(A-PUFFER)

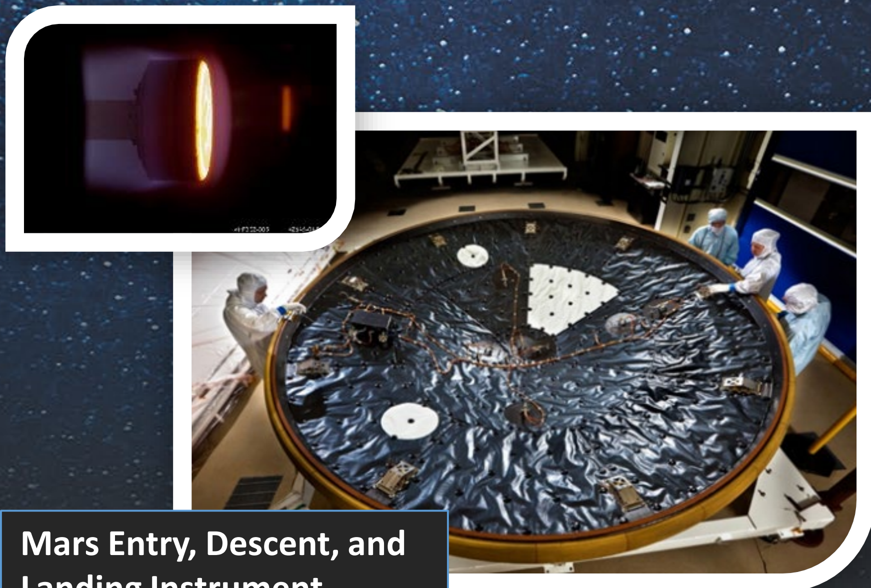


(CADRE design concept)



(Design of first PUFFER mission concept)

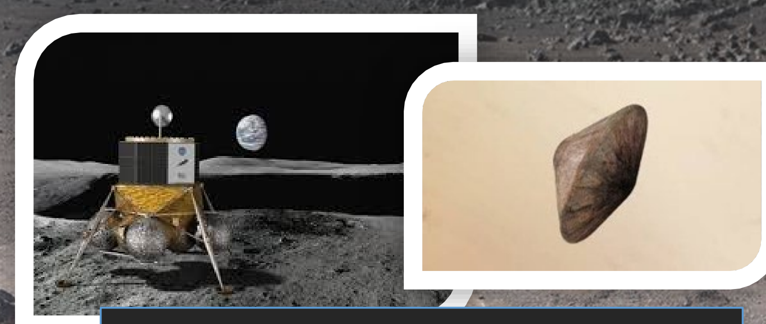
Exploration Technology in Entry, Descent, and Landing



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

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

LeO-based Flight Test Inflatable Decelerator (LOFTID)



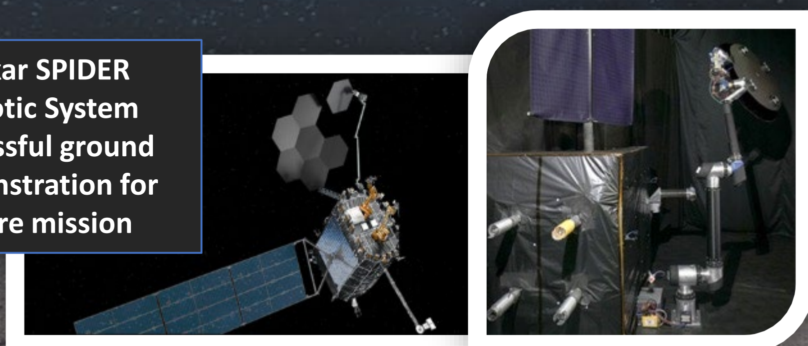
Lander Technologies through awards with Astrobotic and Blue Origin

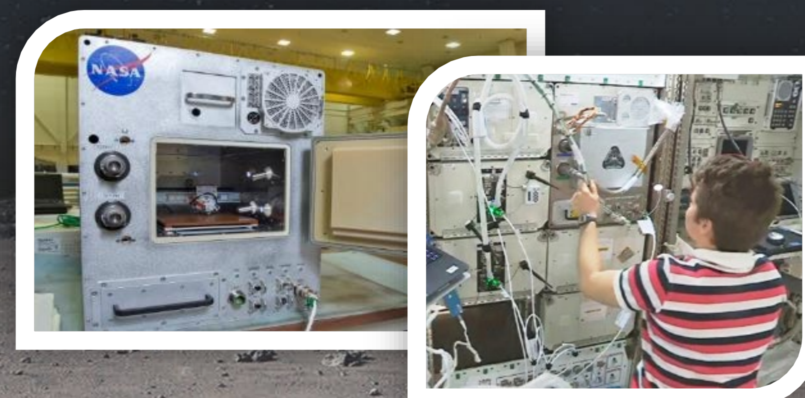
Exploration Technology for On-orbit Servicing, Assembly and Manufacturing

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

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

Maxar SPIDER Robotic System successful ground demonstration for future mission

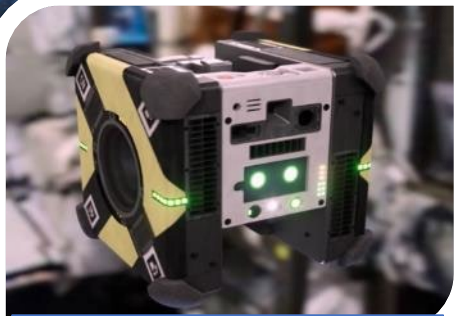




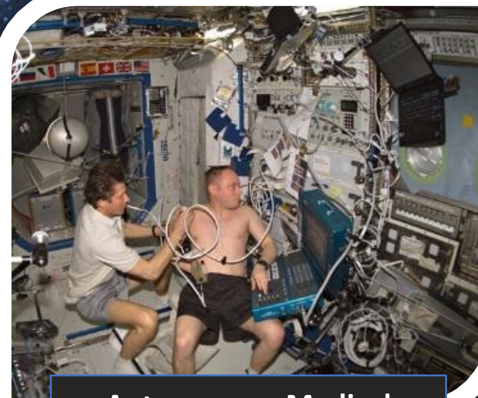
Refabricator is the first integrated 3D printer and recycler in space and aboard ISS. However it experienced a failure with the novel recycler filament extrusion bonding system in 2019. Additional bonder testing will be performed prior to decommissioning. The Refabricator was able to successfully manufacture a tensile specimen on the ISS in Feb. 2020 which will be brought back soon for further testing and evaluation aboard SpaceX-20 in April 2020

OSAM-1 (Satellite Serv & SPIDER) approaching CDR

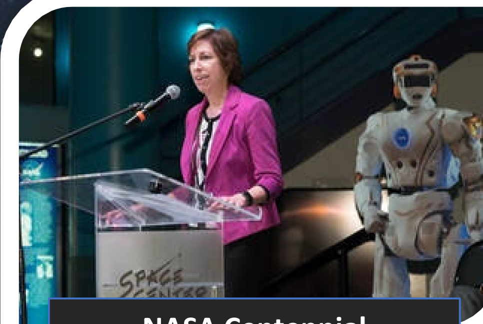
Exploration Technology in Autonomous Systems



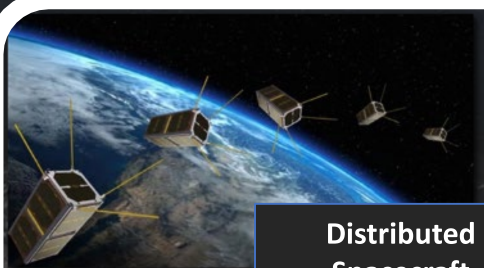
Astrobee- A self-flying robot



Autonomous Medical Operations (AMO)



NASA Centennial Challenges Program Space Robotics Challenge Phase III

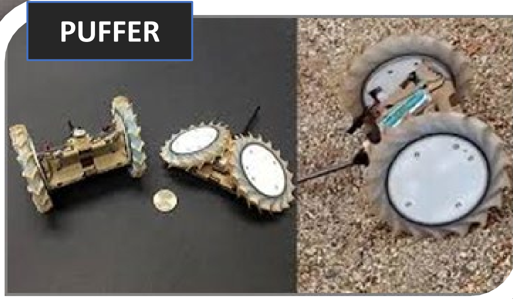


Distributed Spacecraft Autonomy (DSA)

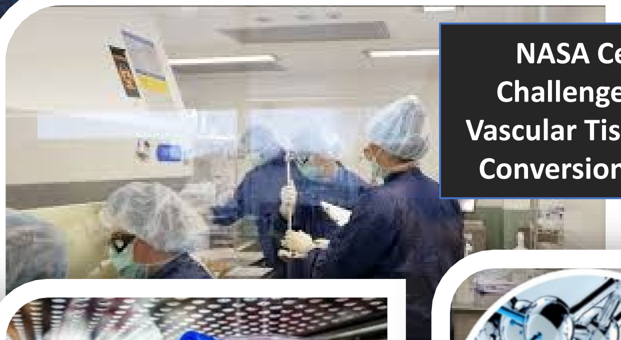
Integrated Systems for Autonomous Adaptive Caretaking (ISAAC)

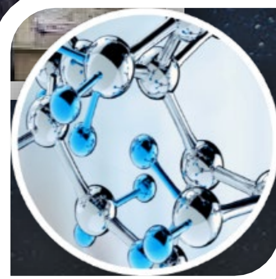
Space Technology Research Institutes (STRI): Smart Deep Space Habitats (SmartHabs) for resilient and autonomous operation.

PUFFER

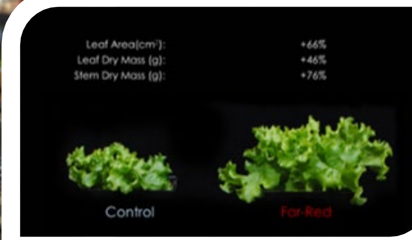


Exploration Technology in Bio Manufacturing



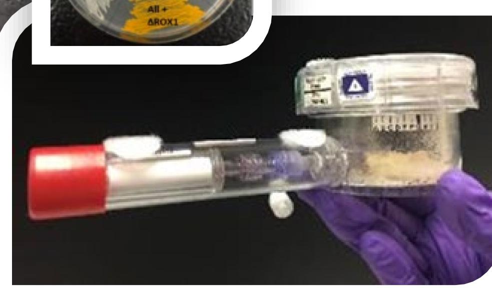


NASA Centennial Challenges Program Vascular Tissue And CO2 Conversion Challenges

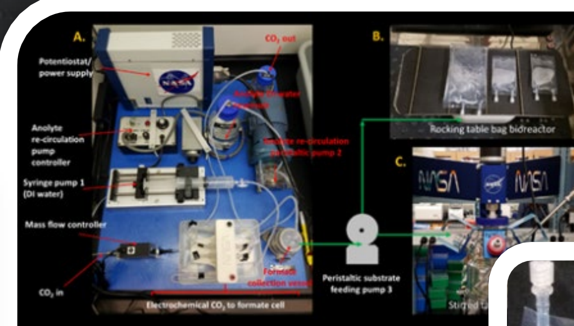


Space Technology Research Institute: The Center for the Utilization of Biological Engineering in Space (CUBES)

Biosensors for Radiation Exposure



In-Space Targeted Nutrient Production



CO2-Based Biomanufacturing

In-Space Manufacturing Overview

Objective: In Space Manufacturing (ISM) Develops and enables the technologies, materials, and processes required to provide affordable, sustainable on-demand manufacturing, recycling, and repair during Exploration missions

Current Status

ISM Multi-Material Fabrication Laboratory (In-Space Metals and Electronics Fabrication)

- Techshot, Inc. successfully completed the Preliminary Design Review (PDR) for the integrated system in June 2019. As of Jan 2020, the ground prototype system is operational and metallic specimen testing and analysis have been completed.
- Tethers Unlimited, Inc. successfully completed the PDR for the autonomous system with in-line inspection capability in October 2019

ISM Recycling and Reuse (In-Space Polymer Fabrication and Recycling)

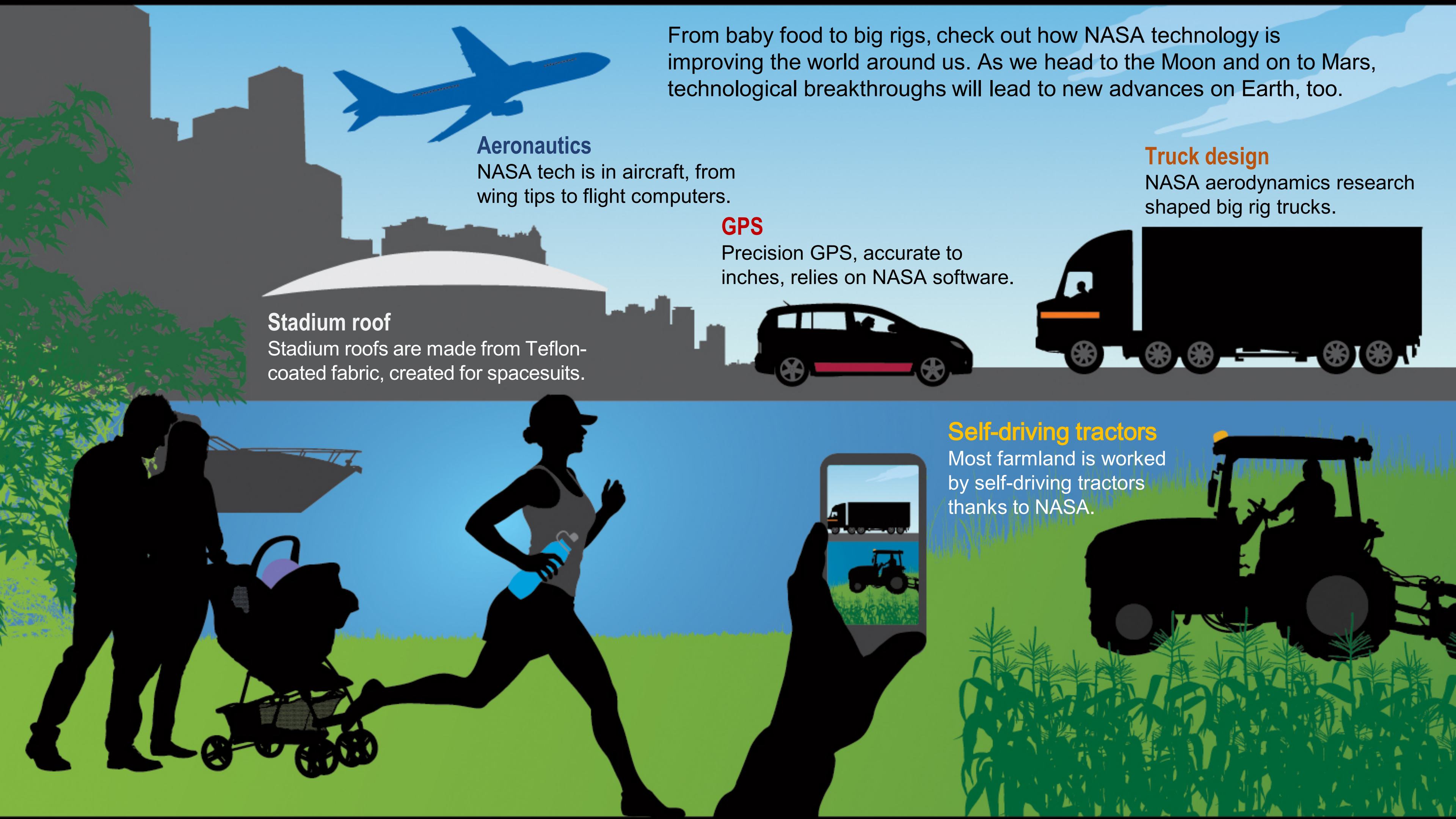
- The Refabricator technology demonstration experienced a failure with the novel recycler filament extrusion bonding system on ISS on 8/2019. Initial analyses indicate that this is a result of thermal properties due to microgravity effects. Additional bonder testing will be performed prior to decommissioning and will provide further insight into the failure.
- The Refabricator was able to successfully manufacture a tensile specimen on the ISS in Feb. 2020. The specimen was printed from pre-loaded filament that was recycled on the ground prior to flight.
- The hardware and samples produced on-orbit will be tested and assessed when returned to Earth on SpaceX-20 in April 2020 and results will be published.

Deliverables/Schedule

- FY20: Incorporate PDR inputs to Fabrication Laboratory design; Refabricator hardware returned and assessed and results published
- FY21 – FY22: ISM Fabrication Laboratory Critical Design Review and verification testing of flight unit to prepare for FY23 ISS demonstration.

Micro-furnace delivered on 12/20/19

There's more Space in your Life than you think!

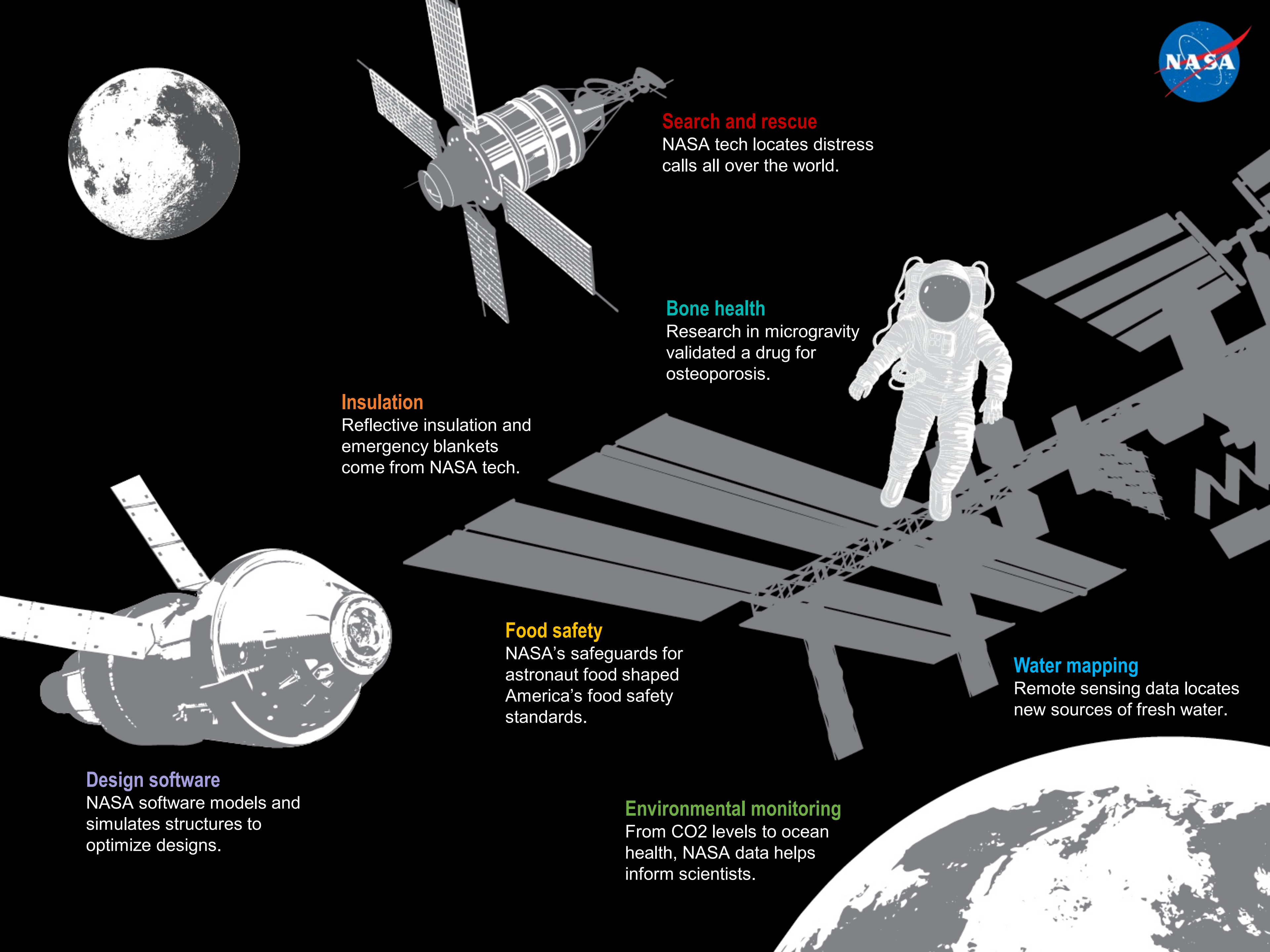


Baby food
NASA synthesized a nutrient found in breast milk, making formula healthier.

Clean water
Nano-technology filters clean water on the go.

Cell phone cameras
Today's digital image sensors were invented by NASA.

Crop forecasts
Farmers rely on satellite data to monitor crops.


Search and rescue
NASA tech locates distress calls all over the world.
Bone health
Research in microgravity validated a drug for osteoporosis.
Insulation
Reflective insulation and emergency blankets come from NASA tech.
Food safety
NASA's safeguards for astronaut food shaped America's food safety standards.
Water mapping
Remote sensing data locates new sources of fresh water.
Design software
NASA software models and simulates structures to optimize designs.
Environmental monitoring
From CO2 levels to ocean health, NASA data helps inform scientists.