National Aeronautics and
Space Administration

Space Technology Mission Directorate

Joint HEO/TI&E NAC Committee Session

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Associate Administrator

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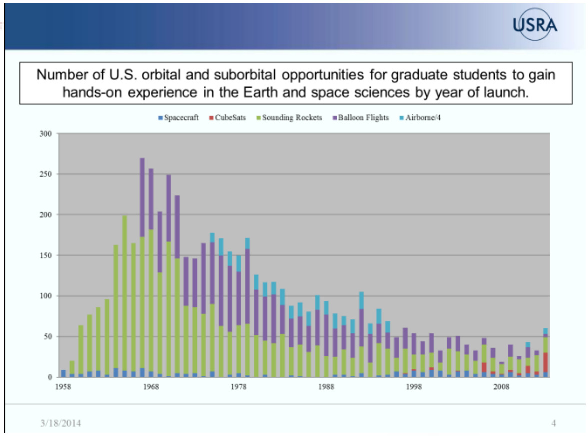
Space Technology…
…. an Investment for the Future

- Enables a **new class of NASA missions** beyond low Earth Orbit.
- **Delivers innovative solutions** that dramatically improve technological capabilities for NASA and the Nation.
- Develops technologies and capabilities that make NASA's missions **more affordable and more reliable.**
- Invests in the economy by **creating markets and spurring innovation** for traditional and emerging aerospace business.
- **Engages the brightest minds** from academia in solving NASA's tough technological challenges.

Value to NASA **Value to the Nation**

Addresses National Needs

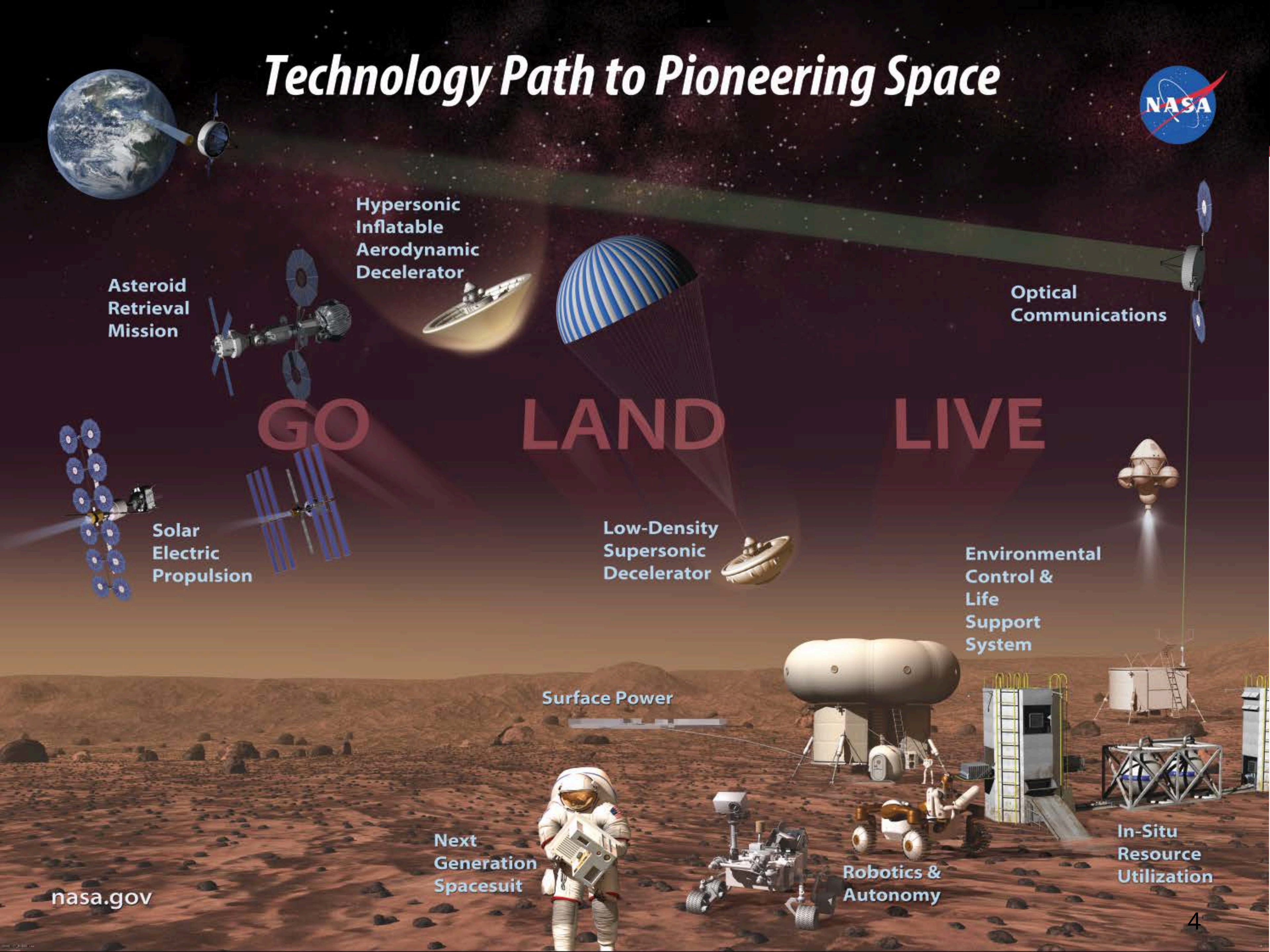
A generation of studies and reports (40+ since 1980) document the need for regular investment in new, transformative space technologies.



Who:
The NASA Workforce
Academia
Small Businesses
The Broader Aerospace Enterprise

Guiding Principles of the Space Technology Programs

- **Adhere to a Stakeholder Based Investment Strategy:** NASA Strategic Plan; NASA Space Tech Roadmaps / NRC Report; NASA Mission Directorate / Commercial advocacy
- **Invest in a Comprehensive Portfolio:** Covers low to high TRL; Grants & Fellowships; SBIR & prize competitions; prototype developments & technology demonstrations
- **Advance Transformative and Crosscutting Technologies:** Enabling or broadly applicable technologies with direct infusion into future missions
- **Develop Partnerships to Leverage Resources:** Partnerships with Mission Directorates and OGAs to leverage limited funding and establish customer advocacy; Public – Private Partnerships to provide NASA resources and support to U.S. commercial aerospace interests
- **Select Using Merit Based Competition:** Research, innovation and technology maturation, open to academia, industry, NASA centers and OGAs
- **Execute with Lean Structured Projects:** Clear start and end dates, defined budgets and schedules, established milestones, lean development, and project level authority and accountability.
- **Infuse Rapidly or Terminate Promptly:** Operate with a sense of urgency; Rapid cadence of tech maturation; informed risk tolerance to implement / infuse quickly or terminate
- **Place NASA at technology's forefront – refreshes Agency's workforce:** Results in new inventions, enables new capabilities and creates a pipeline of NASA and national innovators, and refreshes the agencies technical capabilities / workforce


Technology Path to Pioneering Space
NASA
Hypersonic Inflatable Aerodynamic Decelerator
Asteroid Retrieval Mission
Optical Communications
GO
LAND
LIVE
Solar Electric Propulsion
Low-Density Supersonic Decelerator
Environmental Control & Life Support System
Surface Power
Next Generation Spacesuit
Robotics & Autonomy
In-Situ Resource Utilization
nasa.gov

Technology Drives Exploration

Space Technology Portfolio

Transformative & Crosscutting Technology Breakthroughs

Technology Demonstration Missions bridges the gap between early proof-of-concept tests and the final infusion of cost-effective, revolutionary technologies into successful NASA, government and commercial space missions.

Small Spacecraft Technology Program develops and demonstrates new capabilities employing the unique features of small spacecraft for science, exploration and space operations.

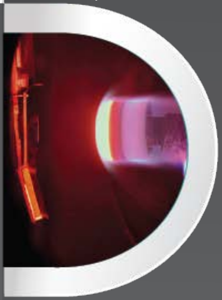
Game Changing Development seeks to identify and rapidly mature innovative/high impact capabilities and technologies that may lead to entirely new approaches for the Agency's broad array of future space missions.

Pioneering Concepts/Developing Innovation Community

NASA Innovative Advanced Concepts (NIAC) nurtures visionary ideas that could transform future NASA missions with the creation of breakthroughs—radically better or entirely new aerospace concepts–while engaging America's innovators and entrepreneurs as partners in the journey.

Space Technology Research Grants seek to accelerate the development of "push" technologies to support future space science and exploration needs through innovative efforts with high risk/high payoff while developing the next generation of innovators through grants and fellowships.

Center Innovation Fund stimulates and encourages creativity and innovation within the NASA Centers by addressing the technology needs of the Agency and the Nation. Funds are invested to each NASA Center to support emerging technologies and creative initiatives that leverage Center talent and capabilities.



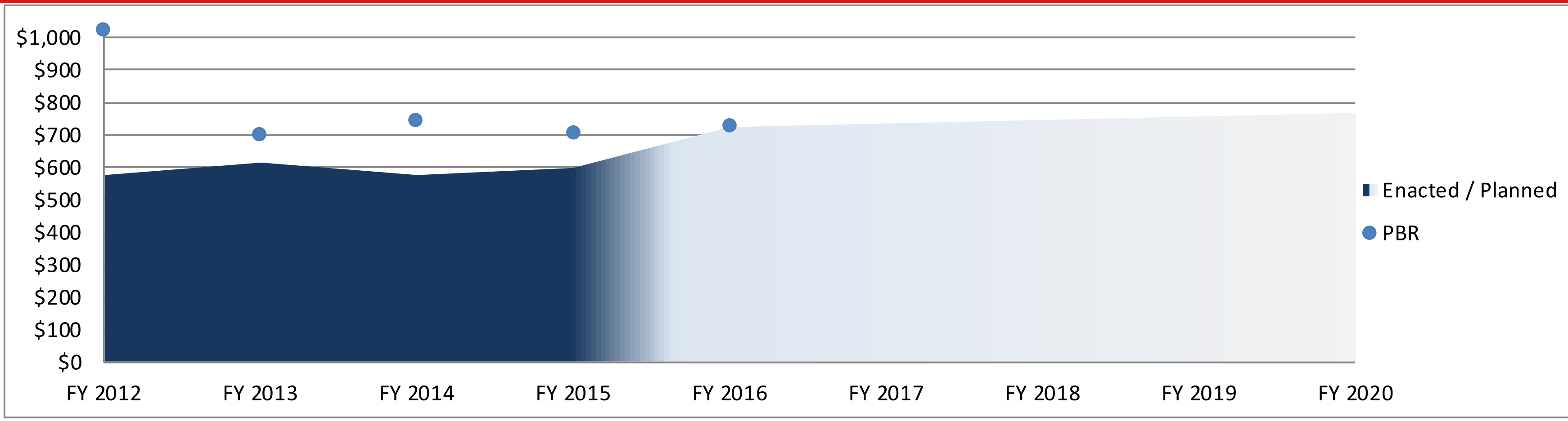
Creating Markets & Growing Innovation Economy

Centennial Challenges directly engages nontraditional sources advancing technologies of value to NASA's missions and to the aerospace community. The program offers challenges set up as competitions that award prize money to the individuals or teams that achieve a specified technology challenge.

Flight Opportunities facilitates the progress of space technologies toward flight readiness status through testing in space-relevant environments. The program fosters development of the commercial reusable suborbital transportation industry.

Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs provide an opportunity for small, high technology companies and research institutions to develop key technologies addressing the Agency's needs and developing the Nation's innovation economy.

STMD FY 2016 President's Budget



	Budget Authority ($M)	Actuals FY 2014	IOP FY 2015	PBR FY 2016	PPBE16 FY 2017	FY 2018	FY 2019	FY 2020
OCT	Agency Technology & Innovation	31	31	33	33	33	33	33
Space Tech Mission Directorate	SBIR and STTR	175	191	201	213	213	213	214
	Space Technology Research & Development	370	374	491	490	500	511	522
	Early Stage Innovation	45		73	75	75	75	75
	Centennial Challenges	1		5	5	5	5	5
	Flight Opportunities	10		15	15	15	15	15
	Small Spacecraft	17		19	17	17	17	17
	Game Changing Development	118		170	179	181	184	191
	Technology Demonstration Missions	180		210	198	208	216	219
	Space Technology Total	576	596	725	736	747	758	769

|--------------NOTIONAL--------------|

STMD & AES Development Objectives

Exploration Technology Development element in STMD

- Develop long-range foundational and transformative technologies and components to support exploration needs (GCD program)
- Conduct flight demonstration missions of high-priority exploration capabilities such as solar electric propulsion (TDM program)
- Mature technologies for infusion into mission-level programs and agency initiatives such as ISS, Orion, SLS, and ARM
- Leverage synergies with game-changing and crosscutting technologies to support multiple customers and mission applications such as SMD, other government agencies, and the commercial sector

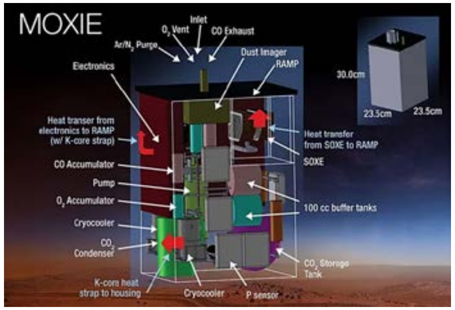
Advanced Exploration Systems program in HEOMD

- Development of exploration systems to reduce risk, lower lifecycle cost, and validate operational concepts for future human missions beyond Earth orbit
- Demonstrate prototype systems in ground test beds, field tests, underwater tests, and ISS flight experiments
- Use and pioneer innovative approaches for affordable rapid systems development and provide hands-on experience for the NASA workforce
- Maintain critical competencies at the NASA Centers and provide NASA personnel with opportunities to learn new and transform skills
- Infuse new STMD/ETD-developed technologies into exploration missions and AES test beds
- Support robotic missions of opportunity to characterize destinations for human exploration

AES – STMD Cooperation Status

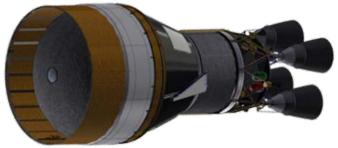
Three major categories of STMD and AES cooperation:

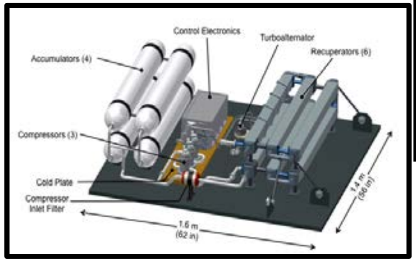
- **Deliveries:** STMD matures technology and delivers to AES for system-level evaluation
  - Examples include Rapid Cycle Amine, Variable Oxygen Regulator, EVA Gloves, and Resource Prospector Mission instruments
- **Partnerships:** STMD and AES co-fund the development of technologies that are of mutual interest
  - Examples include Mars Oxygen ISRU Experiment (MOXIE), Mars EDL Instrumentation 2 (MEDLI-2), and Spacecraft Oxygen Recovery
- **Coordinations:** STMD and AES define specific divisions of responsibility within a technical discipline area
  - Examples include nuclear systems and advanced manufacturing

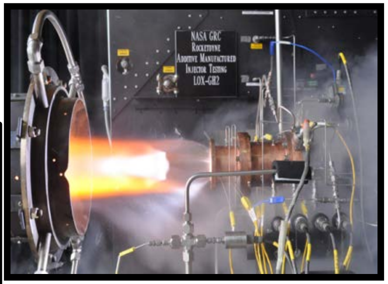


STMD Investments to Advance Future Capabilities of Space Launch System (SLS) & Orion

- Composite cryogenic propellant tanks (CCPT) and Composite Evolvable Upper Stage (CEUS), develops composite technologies for SLS upgrades
- Evolvable Cryogenics (eCryo) develops advanced cryogenic propellant management technologies, and high capacity cryocoolers for SLS future missions
- Additive manufacturing of upper stage injectors, combustion chambers and nozzles for potential SLS upgrades
- Phase change material heat exchangers for Orion in lunar orbit
- 3D Woven ablative TPS for Orion heat shield compression pads
- Advanced oxygen recovery for Orion upgrades

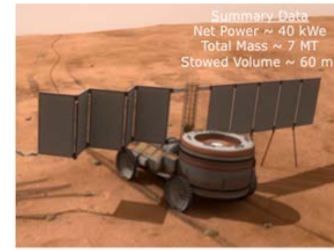


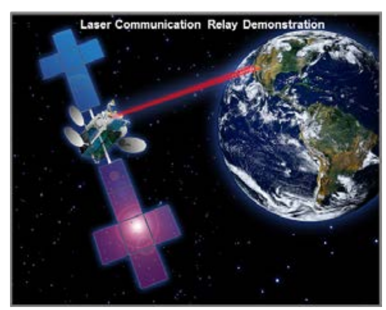




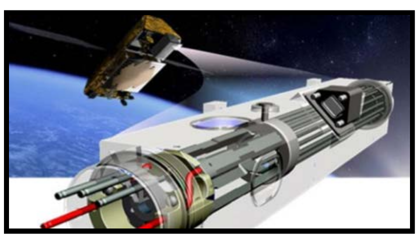
STMD Investments to Advance Human Exploration

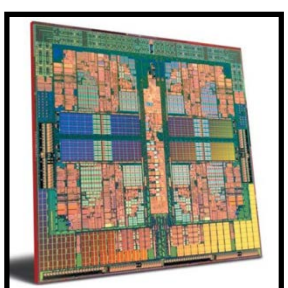
- High Powered SEP – cargo & logistics transportation to Mars
- Small Fission Power / Stirling Cycle – Mars surface power
- HIAD / ADEPT – deployable entry systems for large downmass
- LDSD – supersonic aerodynamic decelerators & supersonic retro-propulsion for the descent of large landed mass at Mars
- Woven TPS – more efficient & flexible TPS materials for entry
- Closed loop air & water recovery – reduced consumables
- Mars atmospheric ISRU (oxygen) – life support and ascent vehicle oxidizer
- Humanoid robotics – enhanced exploration / reduced crew load
- Optical communications – high bandwidth communications





STMD- Aerospace Industry Alignment Examples



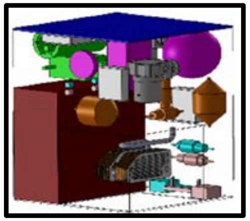


- **Structures and Materials**
  - Composite Exploration Upper Stage (CEUS) – Composite structures for improved launch vehicle performance
  - Manufacturing–Materials, Nanotechnology and Manf. Processes
- **Propulsion & Power**
  - Green Propellant Infusion Mission – improved spacecraft performance & reduced toxicity and ground processing costs
  - Solar Electric Propulsion (SEP) – enabling increased power, reduced mass and longer life for commercial communication satellites
- **Communication & Navigation**
  - LCRD – replacing RF based gateway links with optical links and reduce RF spectrum utilization on commercial satellites
  - Deep Space Atomic Clock – improved timing for next generation GPS satellites
- **Instruments, Sensors, & Robotics**
  - High Performance Spaceflight Computing – for more capable radiation hard avionics for commercial communication satellites
  - Human Robotic Systems (R5) – to perform environmentally hazardous tasks and operate within terrestrial settings

Advancing Mars Capabilities: Progress through Missions to GO and LAND

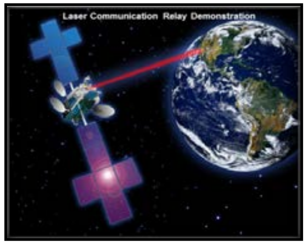
Mars Science Laboratory (MSL)

- First-ever comprehensive **entry, descent, and landing (EDL)** measurements on flight through Martian atmosphere in 2012 landing
- Understanding the Martian environment: measurements of water, atmosphere, and radiation



Mars 2020

- **In-situ resource utilization (ISRU):** Demonstrate oxygen conversion on Mars 2020
- Continue EDL measurements on landing and include first-ever measurements on backshell

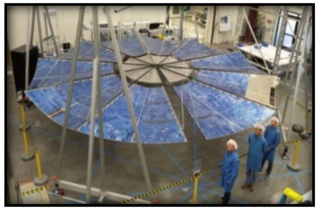


Discovery 2014

- **Thermal protection system (TPS):** New class of materials (woven TPS) in development for Venus entry in Discovery 14 Opportunity
- **Deep-space optical communications**: First-ever demonstration of high-bandwidth communications from deep-space

Orion EM-1

- **Thermal Protection System:** Variant of woven TPS will be flown on EM-1 mission as the compression pads.



Asteroid Redirect Mission

- **In-space propulsion and power:** high-power solar electric propulsion demonstration
- Possible demonstration of high-power solar arrays on ISS

Partnering with Universities to Solve the Nation's Challenges

U.S. Universities have been *very* successful in responding to STMD's competitive solicitations

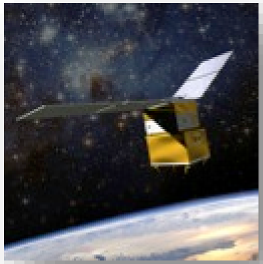
- STMD-funded university space technology research spans the entire roadmap space
- More than **130** U.S. universities have led (*or are STTR partners on*) more than **550** awards since 2011
- In addition, there are many other partnerships with other universities, NASA Centers and commercial contractors

Program	# awards	# University-led awards	Upcoming Opportunities
Space Technology Research Grants 	295	295	• Early Career Faculty • Early Stage Innovations • NASA Space Technology Research Fellowships ***Annually***
NIAC 	93	26	• NIAC Phase I • NIAC Phase II ***Annually***
Game Changing Technology Dev 	37	14	Various topics released as Appendices to SpaceTech-REDDI ***Annually***
Small Spacecraft Technology 	22	13	Smallsat Technology Partnerships – new in 2013 – annual opportunities beginning in 2015
Flight Opportunities 	117	50	Tech advancement utilizing suborbital flight opportunities – NRA to U.S. Universities, non-profits and industry are planned. ***Twice Annually***
STTR 	*192*	*181 w/ univ partners*	*Annual STTR solicitation*
Centennial Challenges 	*4 Challenges (2 university-run)*	*40 teams (9 univ-led, 1 univ-led winner)*	• *One or more challenges annually* • ***Challenge competitions*** *with a* ***procurement track*** *to fund* ***university teams*** *via grants*

Snapshot of Space Technology Partners

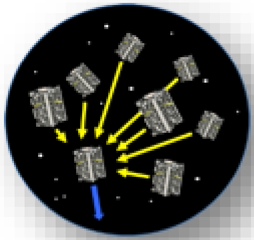
The Aerospace Corporation
Pumpkin Incorporated
tyvak Nano-Satellite Systems LLC
MSNW
BRM Bally Ribbon Mills
Saft
Applied Defense Solutions
Busek
AS Airborne Systems
406 Aerospace
ILC Dover
Micro Aerospace Solutions
L3
Honeybee Robotics
Ball Aerospace & Technologies Corp.
Aerojet Rocketdyne
Honeywell
Aster Labs
Cobham
Draper Laboratory
UP Aerospace
Lockheed Martin
mezzo Technologies
Princeton Lightwave
Teledyne Brown Engineering, Inc — A Teledyne Technologies Company
nanocomp Technologies, Inc.
BAE Systems
United Technologies
DSS Deployable Space Systems
Dynetics — The Power of Solutions
Quest Thermal Group
Surrey Satellite Technology Ltd
Quest Thermal Group
Symmetricom
Moog
Analex Corporation
Nammo
Oceaneering
Boeing
Planetary Systems Corporation
Sierra Lobo
ATK
SEAKR Engineering, Inc.
Frequency Electronics, Inc.
Stinger Ghaffarian Technologies
Southern Research Institute
Space Systems Loral
Virgin Galactic
Orbital
SNC Sierra Nevada Corporation Space Systems
Adcole
PowerSafe Technology Corporation
Masten
MIT Lincoln Laboratory
Microcosm Inc

Key Milestones in 2015-16



Green Propellant: demonstrates propellant formula, thrusters, and integrated propulsion system, for higher performing, safe alternative to highly toxic hydrazine. (Launch STP-2 NET 9/2016)

Deep Space Atomic New space clock improving navigational accuracy for deep space (Launch STP-2 NET 9/2016)



Purchasing major subsystems for **Solar Electric Propulsion and Laser Communications demonstrations**

Small Spacecraft Technology: Four small spacecraft demonstration missions:

- EDSN: Small spacecraft swarm operating as a network for distributed science observations.
- ISARA: Uses a deployed solar array as a Ka-band radio antenna reflector
- OCSD: Demonstrating in-space laser communications using 2 cubesats.
- CPOD: Proximity operations and docking demo with 2 cubesats

Delivers Low Density Supersonic Decelerators

- Conducted second supersonic flight demonstrations of a ring-sail parachute and a supersonic inflatable aerodynamic decelerator.

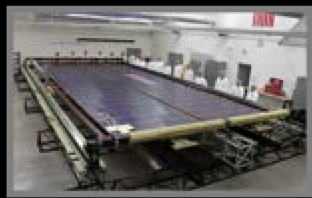
National Aeronautics and
Space Administration

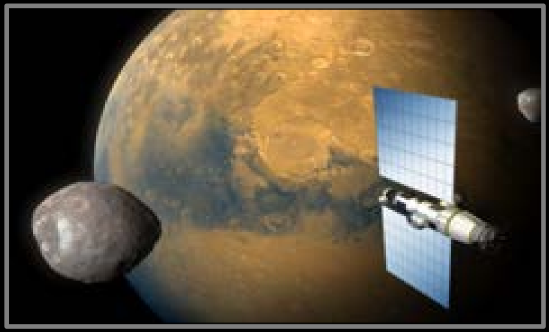
Technology Drives Exploration

www.nasa.gov/spacetech

Technology Investment: High Power Solar Electric Propulsion

Solar Arrays



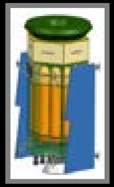


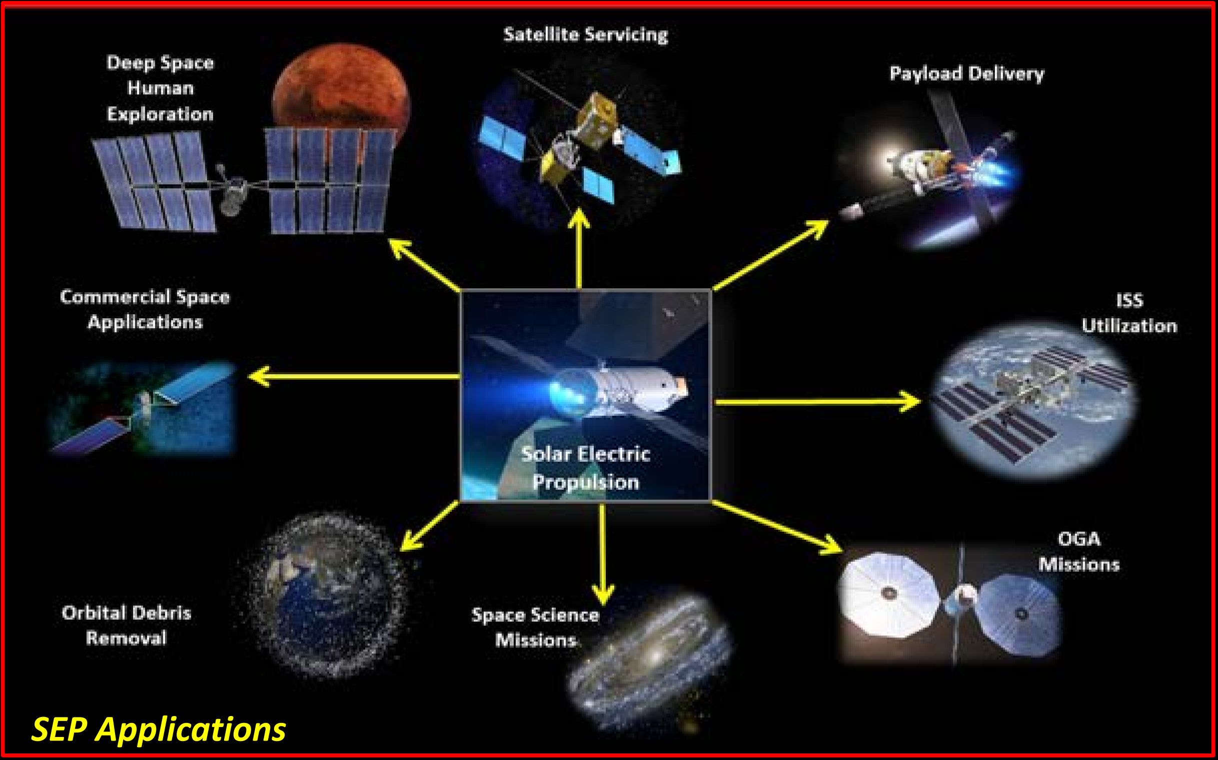
SEP "Space Tugboat"

Power Processing Units (PPUs)

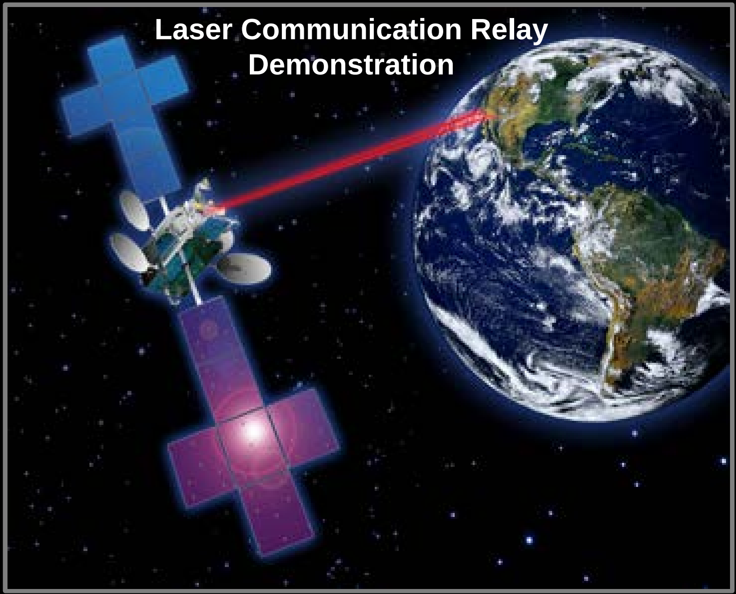
Thrusters

Propellant Feed System & Storage Tanks

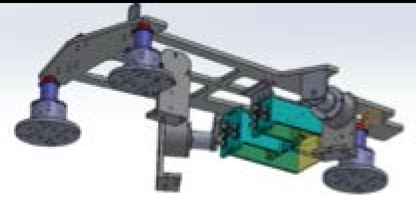




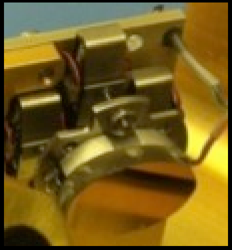
Technology Investment: Optical Space Communication



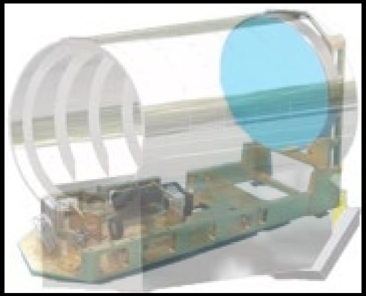
Spacecraft Disturbance Isolation



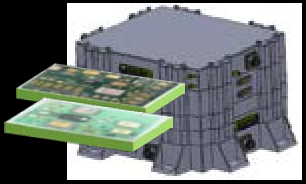
Point-Ahead Mirror



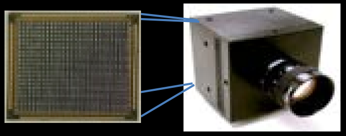
Flight Laser Transceiver

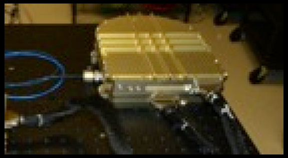


Electronics & Control



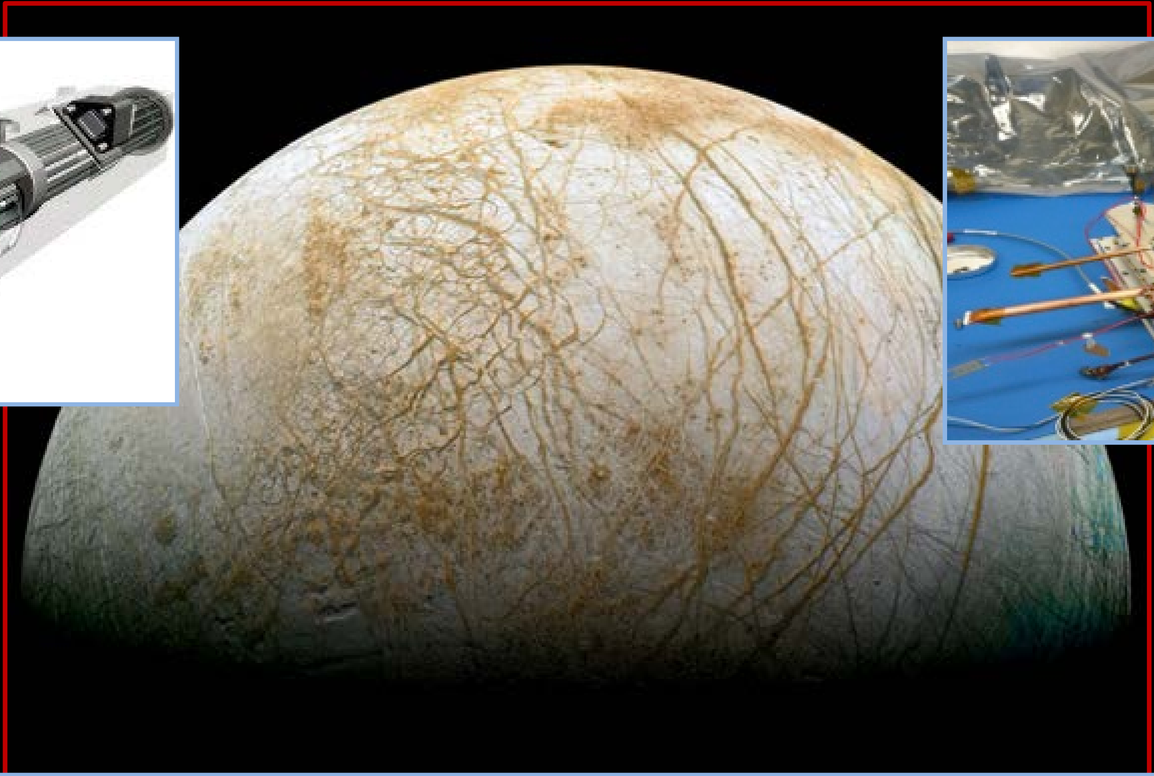
Photon-Counting Camera

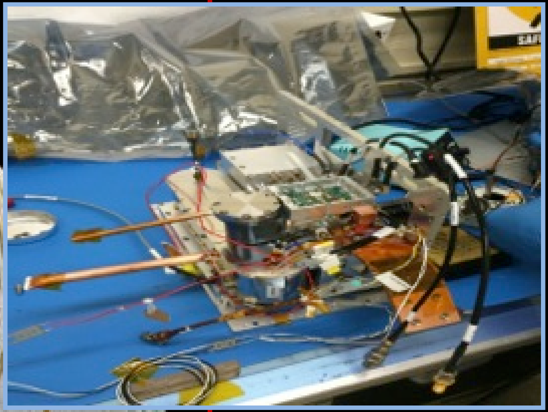




Laser Transmitter

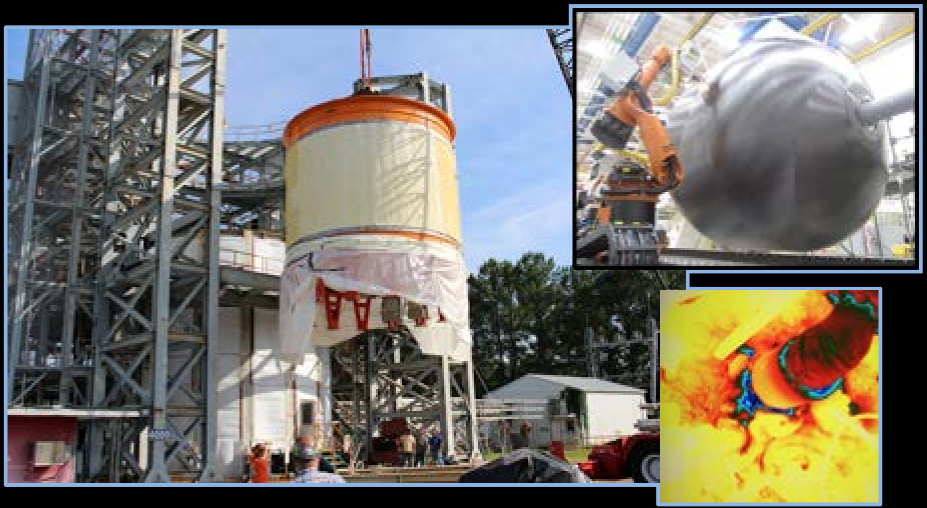
Technology Investment: Deep Space Atomic Clock



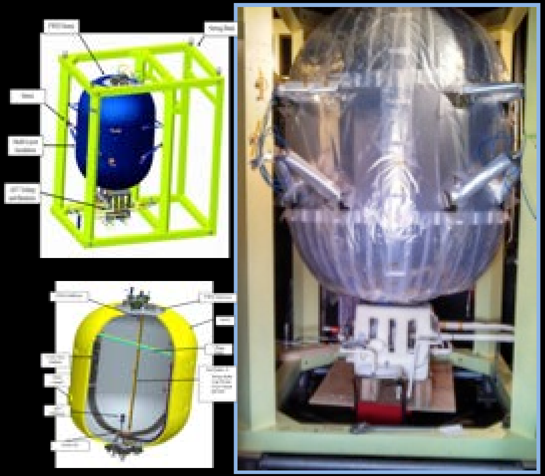


Technology Investment:
Advanced Launch Systems

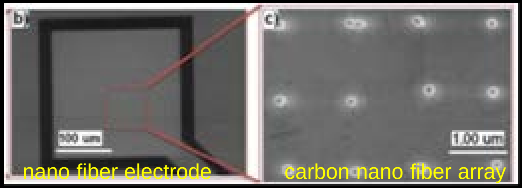
Additive Manufacturing for combustion chambers and nozzles



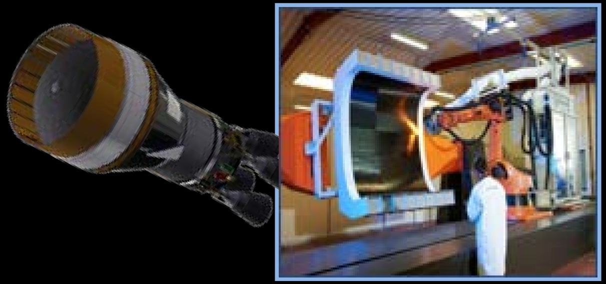
Composite Cryotank and dry structures



eCryo for upper stage



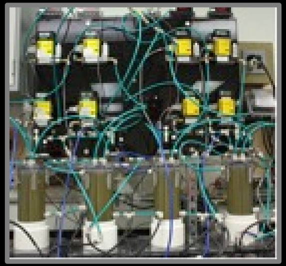
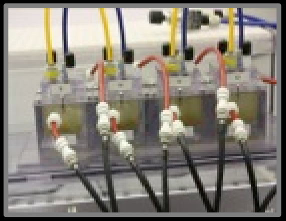
Nanotechnology



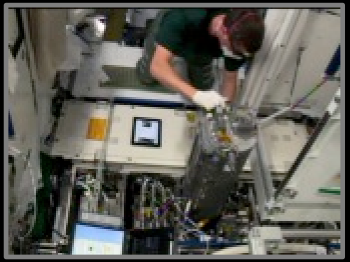
Composites for upper stage

Technology Investment: Advanced Life Support and In-Situ Resource Utilization

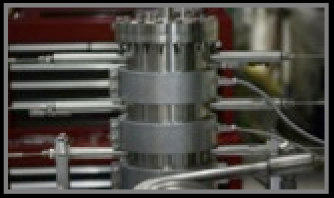
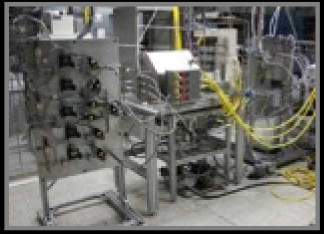


Alternate Water Processor

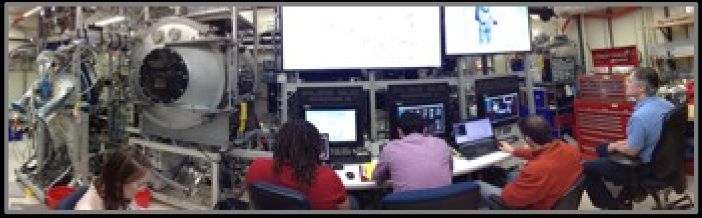



Life Support aboard ISS

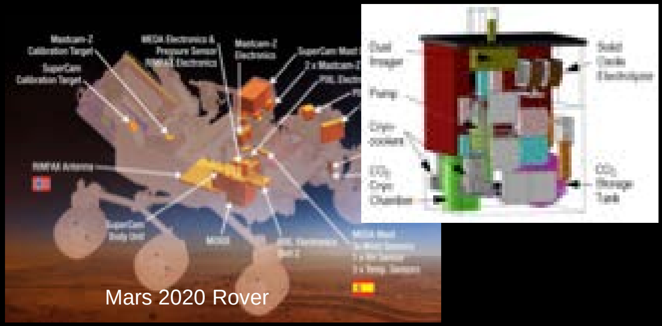



Advanced Oxygen Recovery

Portable Life Support System Integrated Test

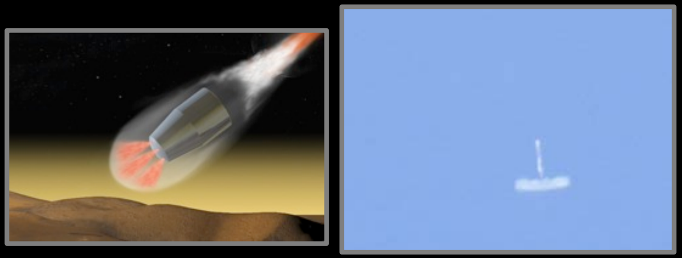


Variable Oxygen Regulator 3.0

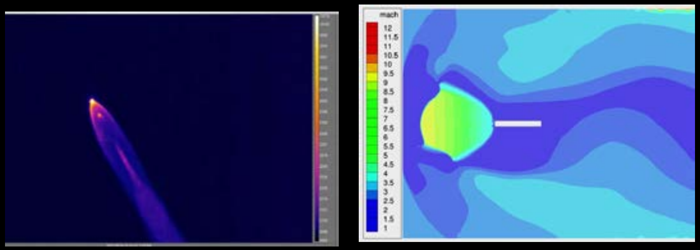


Mars Oxygen ISRU Experiment (MOXIE)

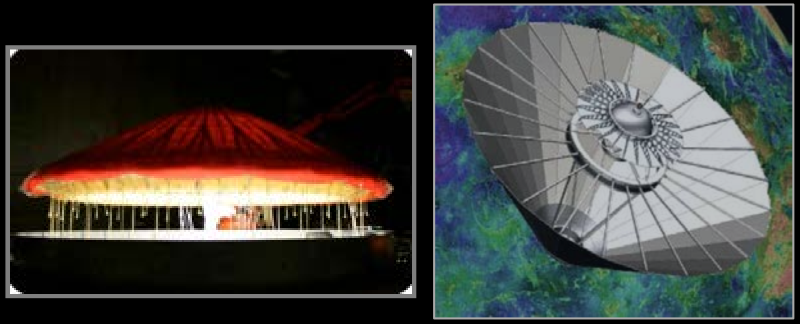
Technology Investment:
Entry, Descent, and Landing



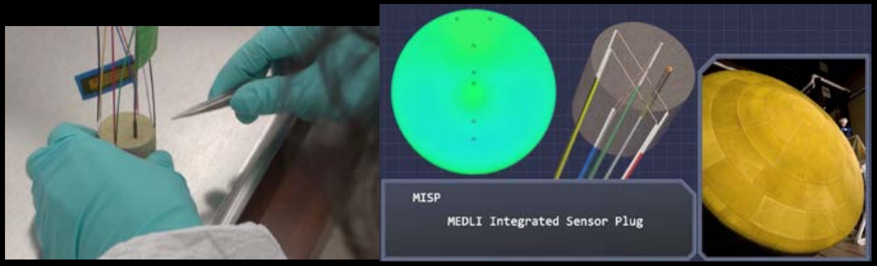
Supersonic Retro Propulsion



Computer Modeling and Data

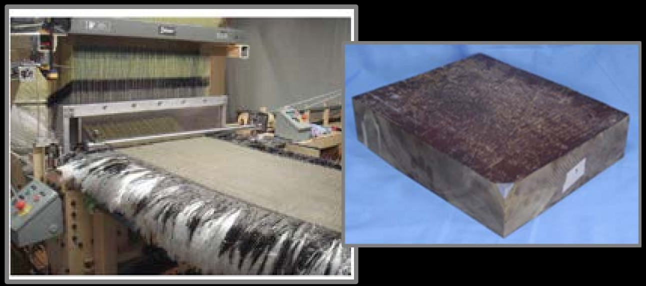


Inflatable (HIAD) or Mechanically Deployable (ADEPT) Entry Systems



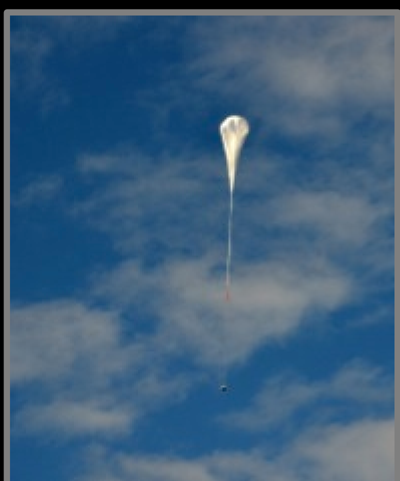
Instrumentation

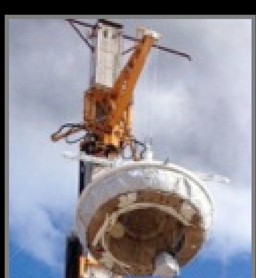
Low Density Supersonic Decelerator



3-D, multi-layer preform weaving technology for thermal protection

Test Success:
Low Density Supersonic Decelerator





Successful LDSD flight test - Creating new knowledge and developing new capability

Working with Other Government Agencies

Currently, significant engagements include:

- Green Propellant Infusion Mission partnership with **Air Force Research Laboratory (AFRL)** propellant and rideshare with **DoD's Space Test Program (STP)**
- **AFRL** collaboration Phase I of a High Performance Space Computing for a low power multi-core processor increasing performance by 100 fold.
- Working with the **USAF Operationally Responsive Space Office (ORS)** for launch accommodations for the Edison Demonstration of Smallsat Networks (EDSN) mission
- Partnership with **DARPA** on "Next Generation Humanoid for Disaster Response"
- Collaboration with **ARPA-e/Dept. of Energy** in new battery chemistries to aide in battery tech development
- Collaboration with **Space Missile Command** developed a Hosted Payload IDIQ contract mechanism for low cost access to space

STMD has ***45 activities*** with ***43 other government agencies***, and ***10 activities*** with ***14 international organizations***. STMD is sharing rides for ***13 activities***.