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.

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

Value to NASA  Value to the Nation

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 Drives Exploration

Space Technology will focus investments in 8 thrust areas that are key to future NASA missions and enhance national space capabilities.

- **High Power Solar Electric Propulsion**
  - Deep space human exploration, science missions with investments in advanced solar arrays and advanced electric propulsion systems, high-power Hall thrusters and power processing units.
  - **Application:** Improved Affordability of commercial and OGA Satellites

- **Space Optical Comm**
  - Substantially increase available bandwidth for near Earth space communications currently limited by power and frequency allocation limits. Increase communications throughput for deep space missions.
  - **Application:** More bandwidth for Commercial and OGA Satellites

- **Advanced Life Support & Resource Utilization**
  - Technologies for human exploration mission including Mars atmospheric In-situ resource utilization, near closed loop air revitalization and water recovery, EVA gloves and radiation protection.
  - **Application:** Air Revitalization for Mining Industry & other closed environments

- **Mars Entry Descent & Landing Systems**
  - Permits more capable science and future human missions to Mars. Includes, hypersonic and supersonic aerodynamic decelerators, next-gen TPS materials, retro-propulsion technology, instrumentation and modeling.
  - **Application:** Human safe Robotics for industrial use, Disaster Response, and Autonomous Operations

- **Space Robotic Systems**
  - Creates future humanoid robotics, autonomy and remote operations technologies to substantially augments the capability of future human space flight missions.
  - **Application:** Industrial Materials and Composites for large transportation structures

- **Lightweight Space Structures**
  - Targets substantial increases in launch mass, and allow for large decreases in needed structural mass for spacecraft and in-space structures.
  - **Application:** Next Generation GPS & launch vehicles

- **Deep Space Navigation**
  - Allows for more capable science and human exploration missions using advanced atomic clocks, x-ray detectors and fast light optical gyroscopes.
  - **Application:** Industrial Materials, Earth Observation

- **Space Observatory Systems**
  - Allows for significant gains in science capabilities including: coronagraph technology to characterize exoplanets, advances in surface materials and better control systems for large space optics.
## 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)

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<td><strong>SBIR and STTR</strong></td>
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<td>Small Spacecraft</td>
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<td>Game Changing Development</td>
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<td>181</td>
<td>184</td>
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<td>Technology Demonstration Missions</td>
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<td><strong>Space Technology Total</strong></td>
<td>576</td>
<td>596</td>
<td>725</td>
<td>736</td>
<td>747</td>
<td>758</td>
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Note: The graph illustrates the enacted/planned and PBR budget for FY 2012 to FY 2020. The table above provides detailed budget authority for various programs under the Space Technology Mission Directorate for FY 2014 to FY 2018.
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
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
**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

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

www.nasa.gov/spacetech
Technology Investment: High Power Solar Electric Propulsion

- **Solar Arrays**
- **Power Processing Units (PPUs)**
- **Thrusters**
- **Propellant Feed System & Storage Tanks**

**SEP Applications**
- Deep Space Human Exploration
- Satellite Servicing
- Payload Delivery
- Commercial Space Applications
- ISS Utilization
- OGA Missions
- Space Science Missions
- Orbital Debris Removal

**SEP “Space Tugboat”**
Technology Investment: Optical Space Communication

- Spacecraft Disturbance Isolation
- Laser Communication Relay Demonstration
- Flight Laser Transceiver
- Electronics & Control
- Photon-Counting Camera
- Laser Transmitter
- Point-Ahead Mirror
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
- Advanced Oxygen Recovery
- Portable Life Support System Integrated Test
- Life Support aboard ISS
- Variable Oxygen Regulator 3.0
- Mars Oxygen ISRU Experiment (MOXIE)
- Mars 2020 Rover
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.