National Aeronautics and
Space Administration

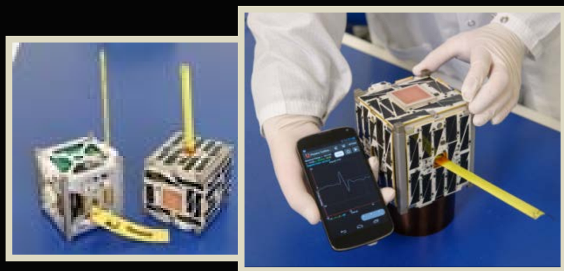
Space Technology Mission Directorate

NAC T&I Committee

Presented by:
Dr. Michael Gazarik
Associate Administrator, STMD

April 2014

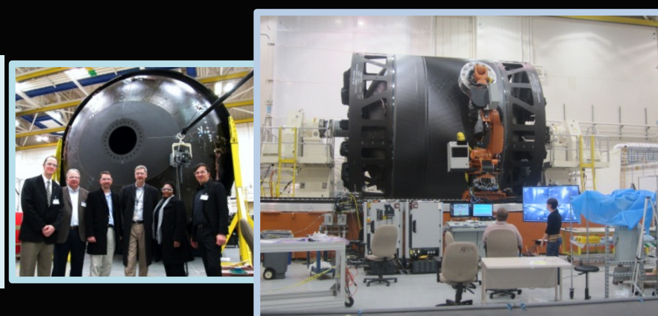
Major Highlights

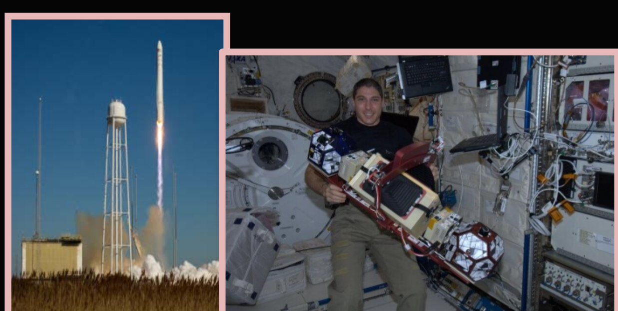


The PhoneSat 2.5 mission will be launched as a rideshare on SpaceX vehicle, to demonstrate command and control capability of operational satellites.

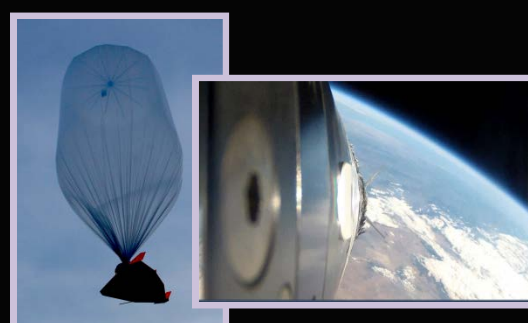
NASA engineers successfully hot-fire tested a 3-D printed rocket engine injector at NASA GRC, marking one of the first steps in using additive manufacturing for space travel.

Successfully fabricated a 5.5-meter composite cryogenic propellant tank and testing at Boeing's facility in Washington and will continue testing at NASA MSFC this year.





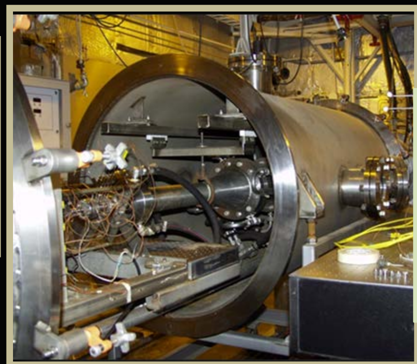
ISS Fluid SLOSH experiment launched on Antares /Orb-1 on Dec. 18, 2014 and now aboard ISS for testing that will be used to improve our understanding of how liquids behave in microgravity



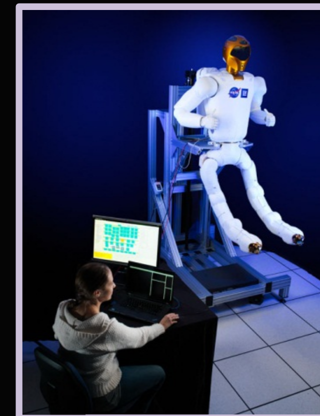
The Flight Opportunities program enabled flight validation of 35 technologies that were tested in space-like environments on four different flight platforms .

At NASA MSFC, the largest 3-D printed rocket engine injector NASA has ever tested blazed to life at an engine firing that generated a record 20,000 pounds of thrust.

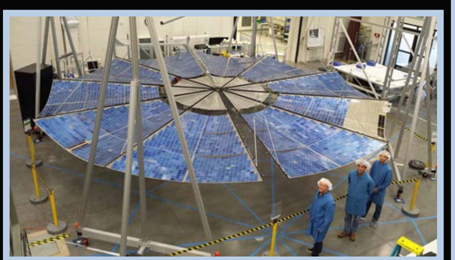
Major Highlights



Green Propellant Infusion Mission took another step closer to infusion by proving capabilities for continuous thrust during testing and is preparing for flight test in 2015.

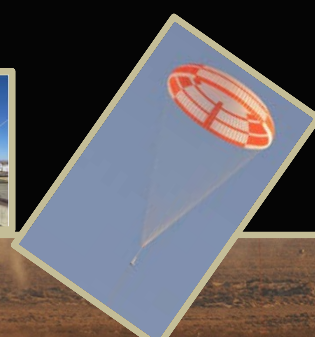


NASA's built and is sending a set of high-tech legs up to the ISS for Robonaut 2 (R2) that will provide R2 the mobility it needs to help with regular and repetitive tasks inside and outside the space station



ATK's “MegaFlex” (left) and DSS “ROSA” (right) solar array are two concepts NASA is maturing to support the development of next generation solar arrays in advancing Solar Electric Propulsion (SEP) technology

Low density supersonic decelerator parachute testing at China Lake, CA. Successfully demonstrated ability to deploy and pull a large parachute with 90,000 pounds of force taking the next steps to landing on Mars.



Surface Telerobotics-
First real-time remote operations of a robotic rover from space and first simulation of human-robot waypoint mission

Space Technology Portfolio

Transformative & Crosscutting Technology Breakthroughs

Pioneering Concepts/Developing Innovation Community

Office of the

Creating Markets & Growing Innovation Economy

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.

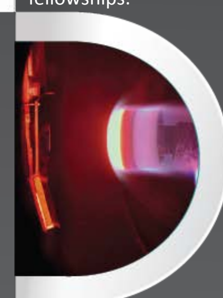
Small Spacecraft Technology Program develops and demonstrates new capabilities employing the unique features of small spacecraft for science, exploration and space operations.

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.

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.



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.

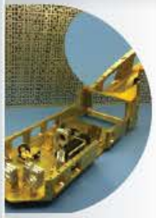
Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs provide an opportunity for small, high technology companies and research institutions to develop key technologies addressing the Agency's needs and developing the Nation's innovation economy.

Deep Space Exploration is Near

Space Technology will focus investments in 8 key thrust areas that will enable or substantially enhance future NASA mission capabilities.

High Power Solar Electric Propulsion

Deep space human exploration, science missions and commercial applications with investments in advanced solar arrays and advanced electric propulsion systems, high-power Hall thrusters and power processing units.



Space Optical Comm.

Substantially increase the available bandwidth for near Earth space communications currently limited by power and frequency allocation restrictions, and increase the communications throughput for a deep space mission.

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.

Mars Entry Descent and Landing Systems

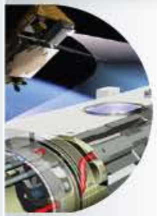
Permits more capable science missions, eventual human missions to mars including, hypersonic and supersonic aerodynamic decelerators, a new generation of compliant TPS materials, retro-propulsion technologies, instrumentation and modeling capabilities.

Space Robotic Systems

Creates future humanoid robotics, autonomy and remote operations technologies to substantially augments the capability of future human space flight missions.

Lightweight Space Structures

Targets substantial increases in launch mass, and allow for large decreases in needed structural mass for spacecraft and in-space structures.



Deep Space Navigation

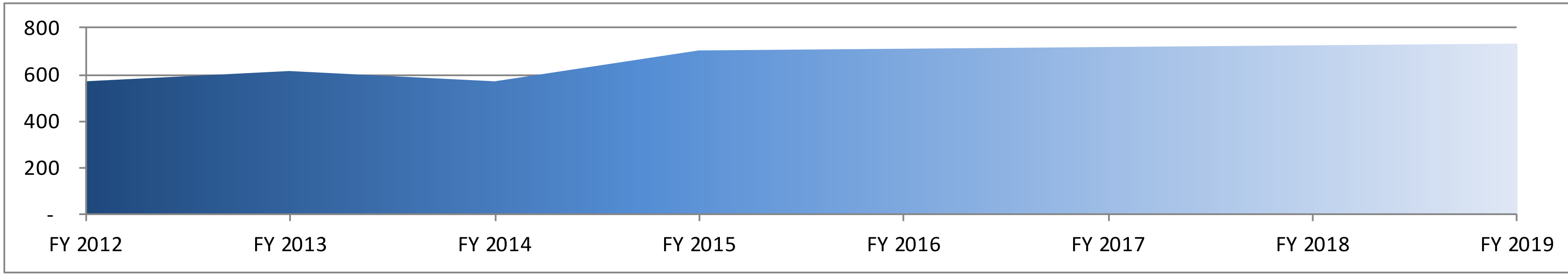
Allows for more capable science and human exploration missions using advanced atomic clocks, x-ray detectors and fast light optical gyroscopes.

Space Observatory Systems

Allows for significant increases in future science capabilities including, AFTA/WFIRST coronagraph technology to characterize exo-planets by direct observation and advances in the surface materials as well as control systems for large space optics.

THRUST AREAS

STMD FY2015 President's Budget

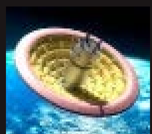


	Budget Authority ($M)	FY 2015	Notional FY 2016	FY 2017	FY 2018	FY 2019
	FY 2015 President's Budget Request	**706**	**713**	**720**	**727**	**734**
OCT	Partnership Developments and Strategic Integration	**34**	**34**	**34**	**34**	**34**
Space Tech Mission Directorate	SBIR and STTR	**191**	**201**	**212**	**212**	**212**
	Crosscutting Space Tech Development	**257**	**190**	**186**	**199**	**204**
	Early Stage Innovation	67	67	68	69	69
	Flight Opportunities	15	15	15	15	15
	Small Spacecraft	17	17	17	17	17
	Game Changing Development	50	45	49	36	39
	Technology Demonstration Missions	106	46	36	61	63
	Exploration Technology Development	**224**	**288**	**288**	**282**	**285**
	Game Changing Development	103	129	126	132	129
	Technology Demonstration Missions	121	159	162	150	156

*Numbers do not total due to rounding

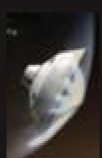
CY Major Events & Milestones

2012



HIAD
IRVE 3

Human Robotic
Systems &
Telerobotics



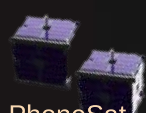
MEDLI

LDSD Supersonic
Inflatable Aerodynamic
Decelerator

2013

Human Robotic
Systems &
Telerobotics

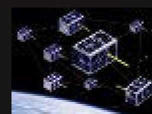
PhoneSat
1 & 2.0



PhoneSat
2.4 & 2.5

2.4m
Composite
Cryotank

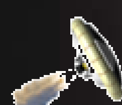
2014



EDSN
SmallSat
Demo

Human Robotic
Systems &
Telerobotics

5.5m
Composite
Cryotank



LDSD: Supersonic Inflatable
Aerodynamic Decelerator

2015

Optical Comm
& Sensor
Demo

Sunjammer
Solar Sail

Integrated
Solar Array

Cubesat
Proximity
Ops Demo

Deep Space
Atomic Clock

Green
Propellant

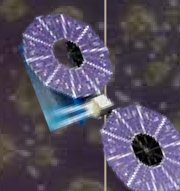
2016

2017

2018

Cryogenic
Propellant
Storage &
Transfer

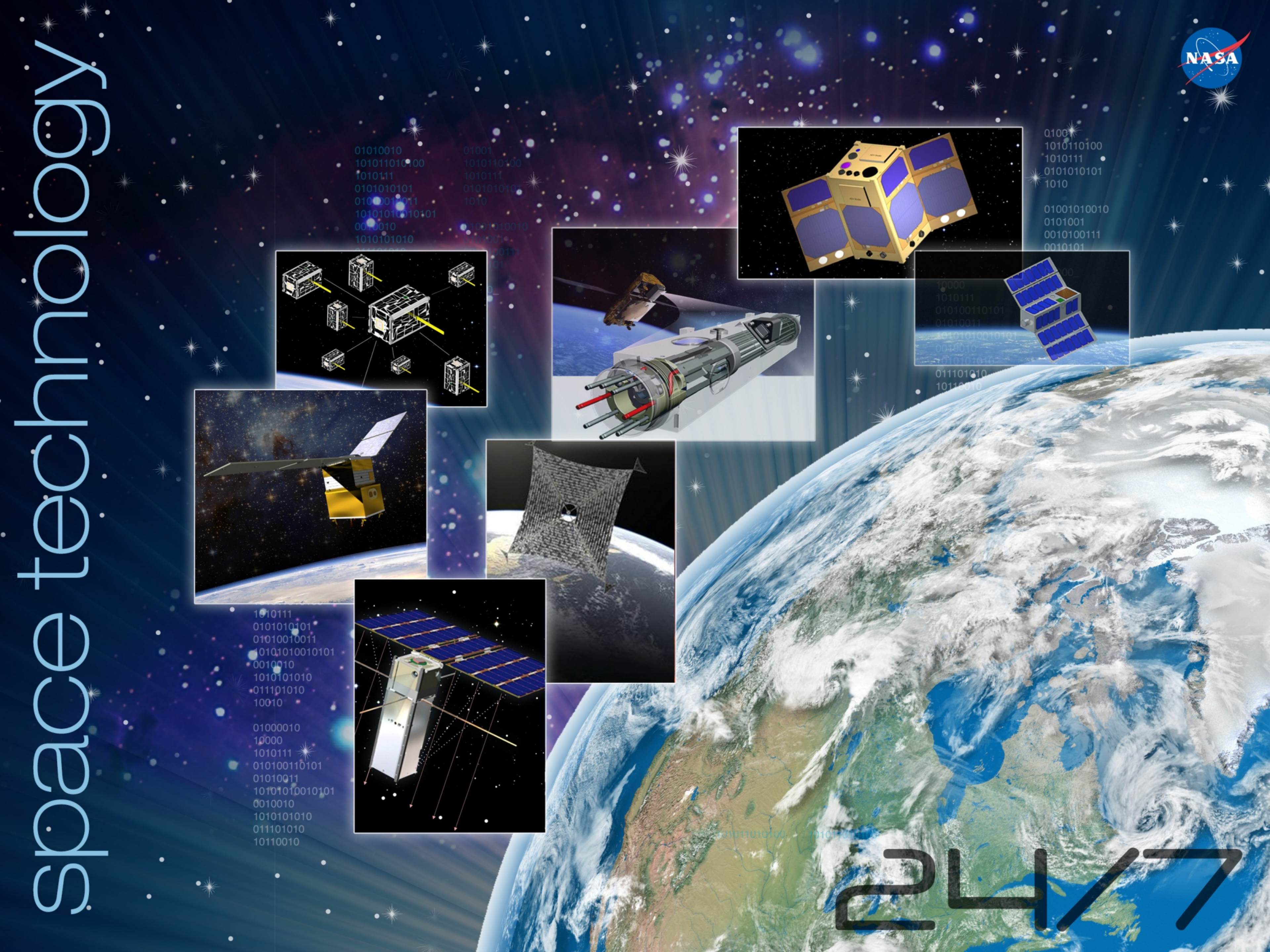
Laser
Communications
Relay
Demonstration



SEP Demo
Mission

2019

Future Planning

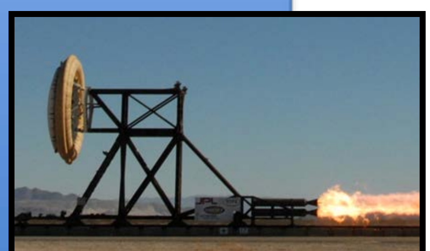


space technology
NASA
24/7

Technology Success: Low Density Supersonic Decelerator

Integration of Supersonic Inflatable Aerodynamic Decelerator (SIAD) onto first flight demonstration vehicle;
Top, inflated for dimensional verification;
Middle, deflated, being packaged;
Bottom, completed packaging

Successful test firing of Ballute mortar (used to deploy supersonic parachute)



Rocket sled testing of robotics-class supersonic decelerator

Project Summary: *Developing technologies to use atmospheric drag to dramatically slow a vehicle as it penetrates the skies over worlds beyond our own. Developing the largest ever supersonic parachute ever developed for Mars entry – potential infusion in the Mars 2020 mission.*

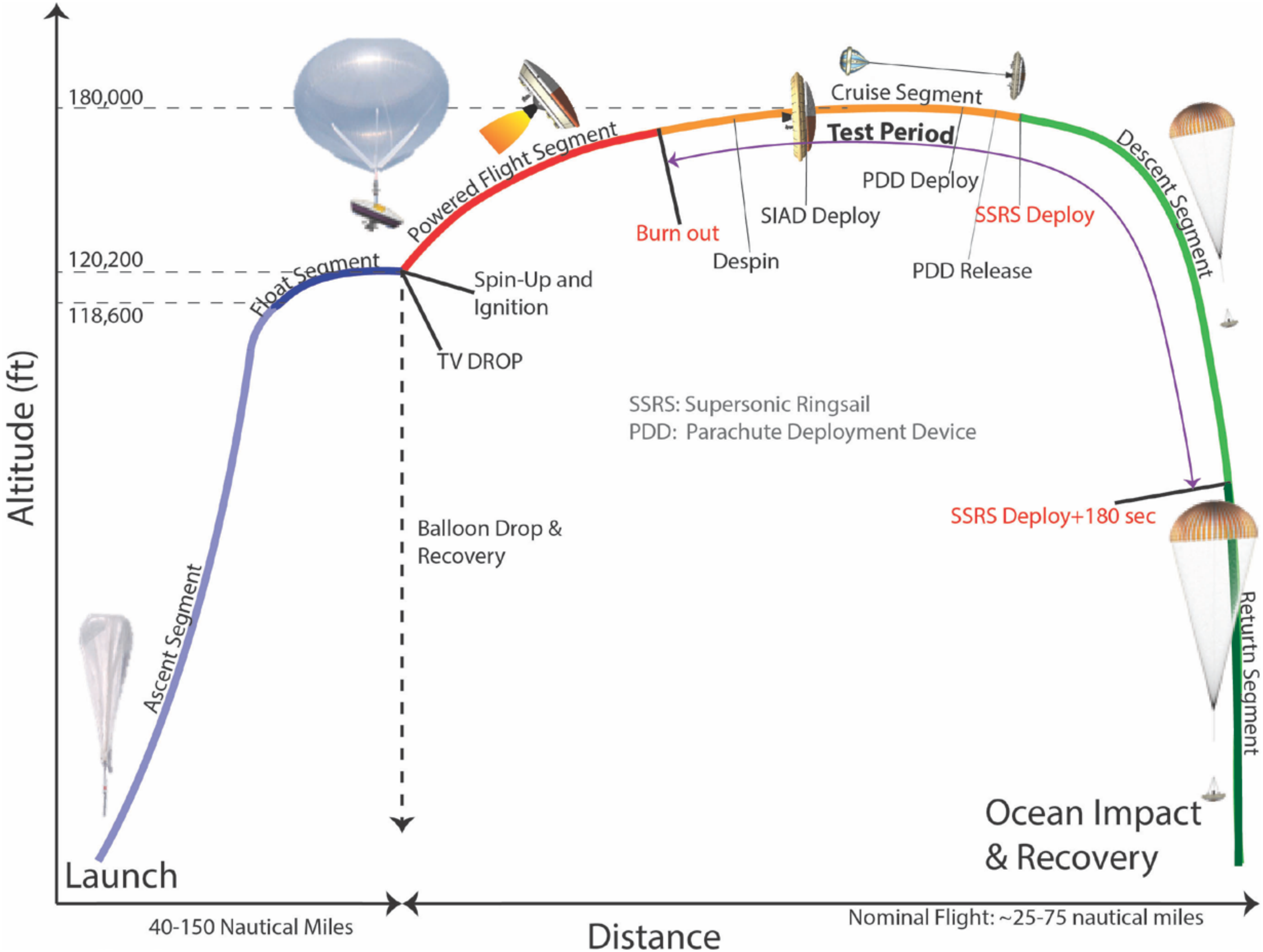
Accomplishments:

- Successfully performed two rocket sled tests on a robotics-class supersonic decelerator
- Wind tunnel tested 30 different parachute configurations
- Conducted two static balloon launch tests
- Successfully tested GLN-MAC navigation computer on two sounding rocket launches
- Thermal/Vacuum testing of ballute inflation aid and camera system

Plans:

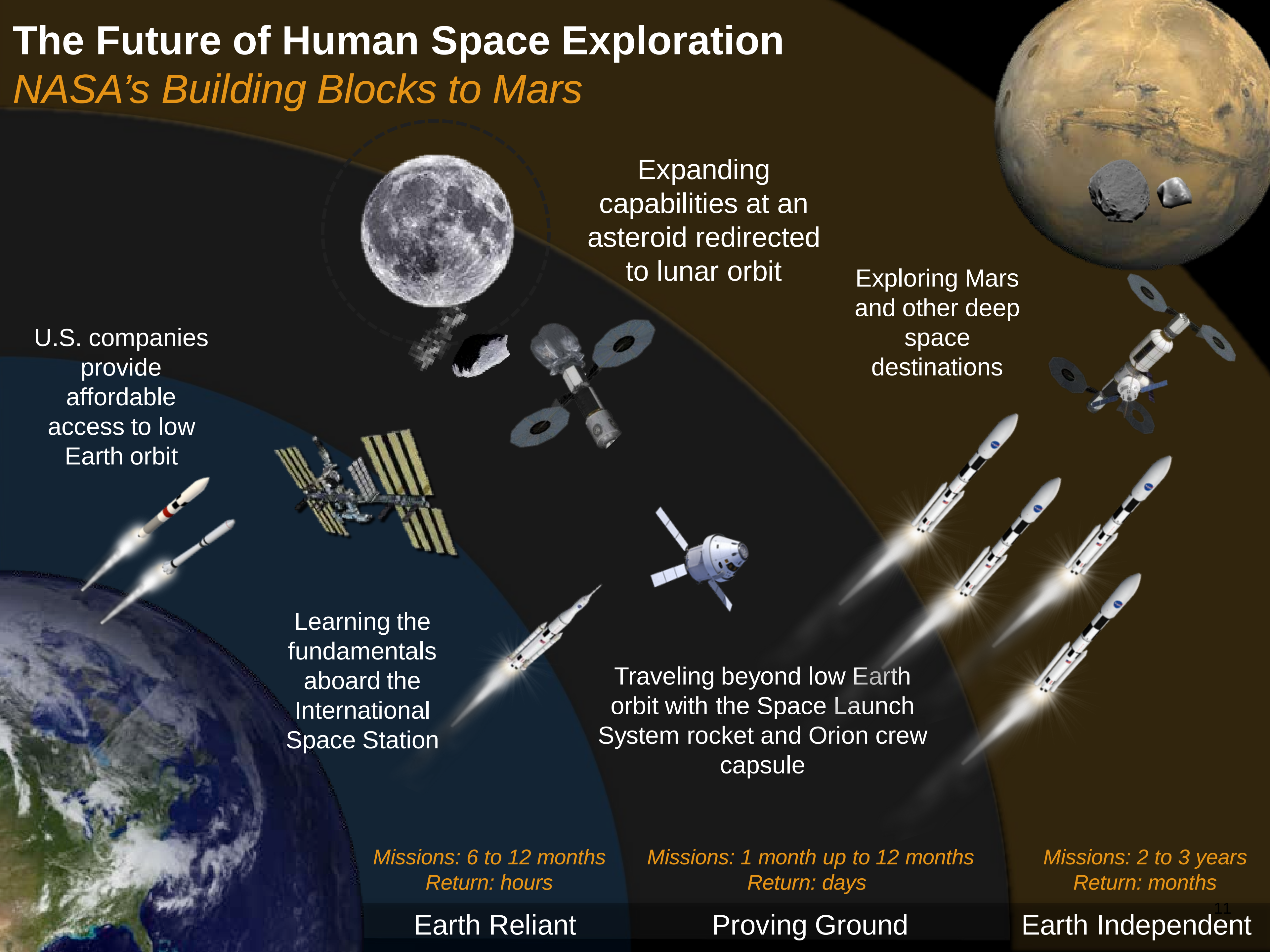
- Assembly, Integration & Test of first supersonic flight demonstration vehicle
- Conduct first ever atmospheric supersonic flight test of an inflatable decelerator system

LDSD Supersonic Flight Plan
June 2014

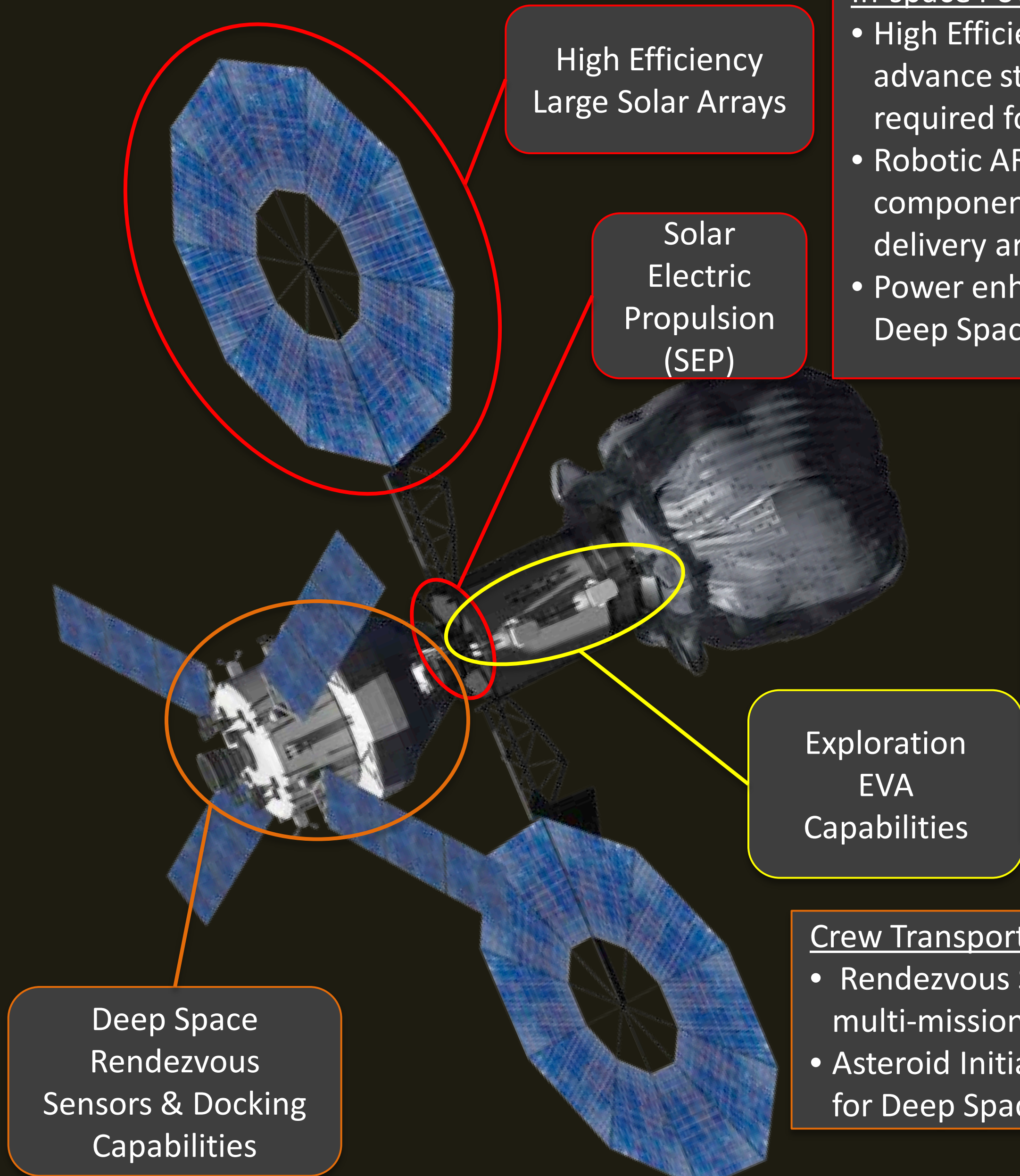


The Future of Human Space Exploration

NASA's Building Blocks to Mars



Asteroid Redirect Mission Provides Capabilities For Deep Space/Mars Missions



In-space Power and Propulsion :

- High Efficiency Solar Arrays and SEP advance state of art toward capability required for Mars
- Robotic ARM mission 50kW vehicle components prepare for Mars cargo delivery architectures
- Power enhancements feed forward to Deep Space Habitats and Transit Vehicles

EVA:

- Build capability for future exploration through Primary Life Support System Design which accommodates Mars
- Test sample collection and containment techniques including planetary protection
- Follow-on missions in DRO can provide more capable exploration suit and tools

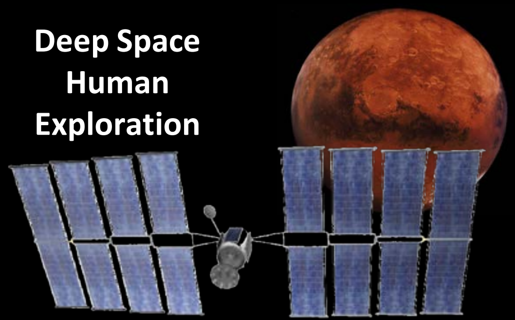
Crew Transportation and Operations:

- Rendezvous Sensors and Docking Systems provide a multi-mission capability needed for Deep Space and Mars
- Asteroid Initiative in cis-lunar space is a proving ground for Deep Space operations, trajectory, and navigation.

High-powered SEP Enables Multiple Applications

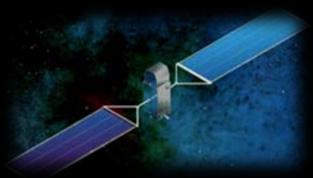
Satellite Servicing

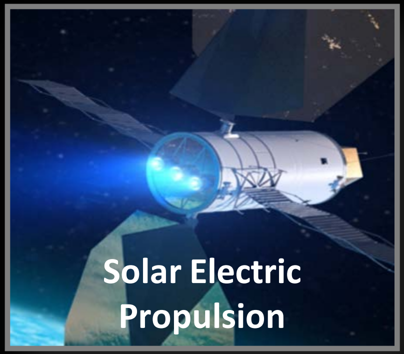
Deep Space Human Exploration



Payload Delivery

Commercial Space Applications



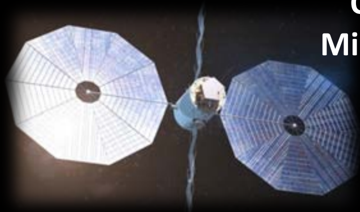


ISS Utilization

Orbital Debris Removal

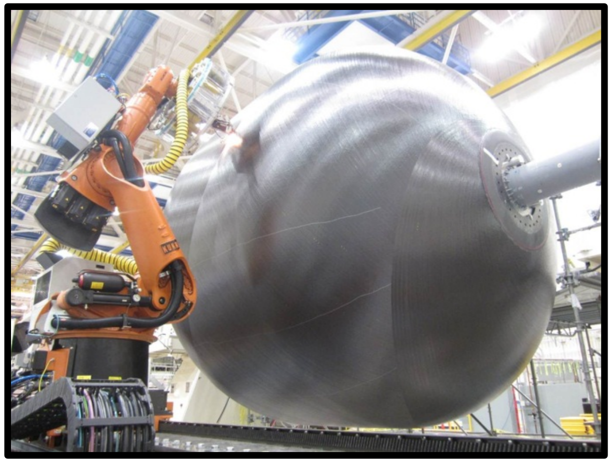
Space Science Missions

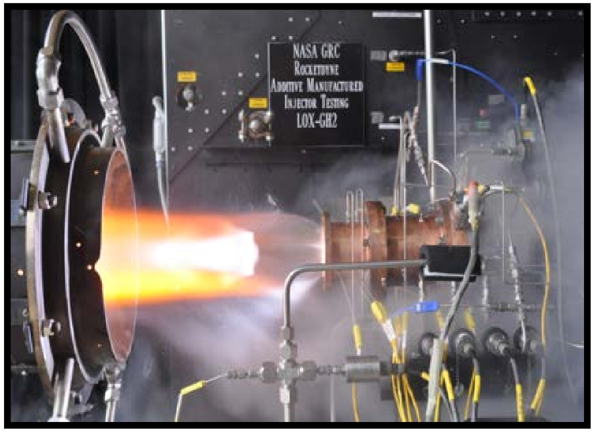
OGA Missions



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

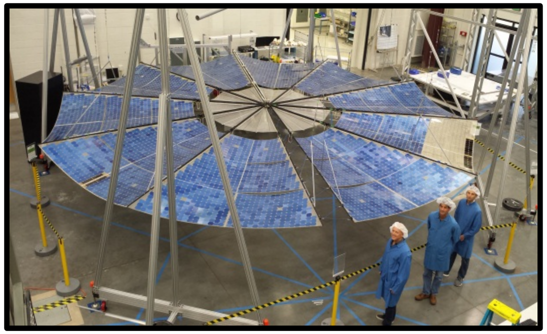
- Composite cryogenic propellant tanks and dry structures for SLS block upgrades
- Cryogenic propellant storage and transfer for upper stage block upgrades
- Additive manufacturing and testing of upper stage injectors, combustion chambers and nozzles
- Phase change material heat exchangers for Orion in lunar orbit
- Woven TPS for Orion heat shield compression pads
- Advanced air revitalization for Orion upgrades

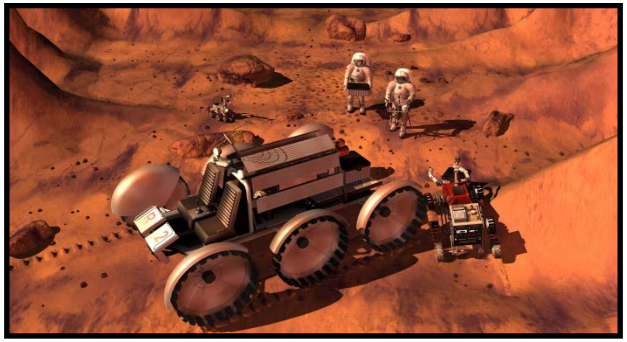


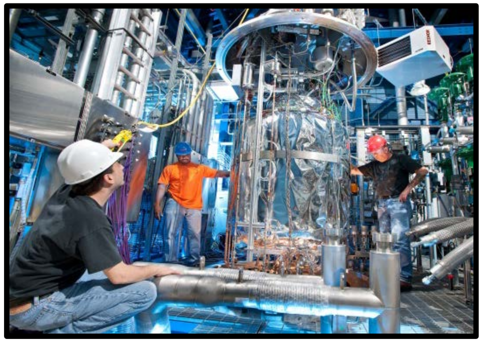


STMD Investments to Advance Human Exploration of Mars

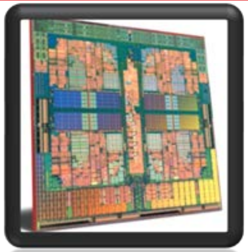
- High Powered SEP – cargo and logistics transportation to Mars
- CPST – either chemical or nuclear thermal in-space propulsion for crew transportation
- Composite cryogenic propellant tanks and dry structures – exploration upper stage
- Small Fission Power / Stirling Engine Power – Mars surface power
- HIAD / ADEPT – deployable entry systems for large mass landers
- LDSD – supersonic descent of large landed mass at Mars
- Woven TPS – more efficient and flexible TPS materials for entry
- Advanced close loop Air revitalization and water recovery – reduced consumables
- Mars atmospheric ISRU (oxygen) – life support and ascent vehicle oxidizer
- Humanoid robotics – enhanced exploration and crew workload relief
- Advanced mobility rover – remotely operated exploration
- Optical communications – high bandwidth communications at Mars

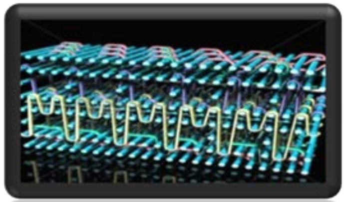






STMD Investments to Advance Outer Planetary Exploration

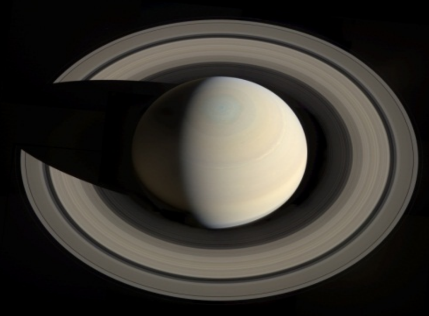




STMD is developing TPS and deep space communication technologies for infusion in SMD's Discovery 2014

Technologies in FY15

- Deep Space Optical Communications
- Deep Space Atomic Clock
- High Performance Space Computing
- Small Nuclear Fission / Sterling Power (kilo-power)
- Woven TPS for aerocapture and outer-planetary entry
- Europa Ice Penetration Challenge



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
- Draper Laboratory
- UP Aerospace
- Princeton Lightwave
- Cobham
- Teledyne Brown Engineering, Inc (A Teledyne Technologies Company)
- L'Garde Est. 1971
- nanocomp Technologies, Inc.
- BAE Systems
- United Technologies
- DSS Deployable Space Systems
- 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
- Lockheed Martin
- Space Systems Loral
- Virgin Galactic
- Orbital
- SNC Sierra Nevada Corporation Space Systems
- PowerSafe Technology Corporation
- MIT Lincoln Laboratory
- Microcosm Inc
- Adcole
- Masten

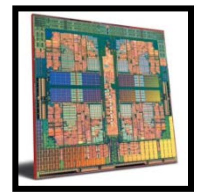
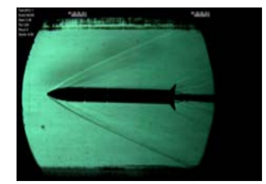
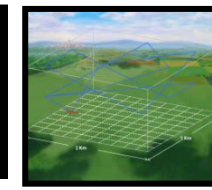
Collaborations with Other Government Agencies

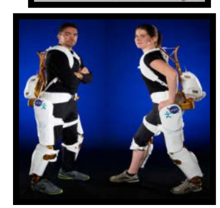
STMD has ***45 activities*** with ***43 other government agencies***, and ***10 activities*** with ***14 international organizations***. STMD is sharing rides for ***13 activities***.

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)**
- Solar Sail Demonstration partnership with **NOAA**
- **AFRL** collaboration Phase I of a High Performance Space Computing for a low power multi-core processor increasing performance a 100 fold.
- Soldier-Warfighter Operationally Responsive Deployer for Space (SWORDS) low-cost nano-launch system with **Army**
- UAS Airspace Operations Prize Challenge coordinated with **FAA**
- Working with the **USAF Operationally Responsive Space Office (ORS)** for launch accommodations for the Edison Demonstration of Smallsat Networks (EDSN) mission.
- Partnership for Ohio's first hydrogen generating fueling station with **Greater Cleveland Regional Transit Authority** to power city bus
- Partnership with **DARPA** on "Next Generation Humanoid for Disaster Response"
- In discussion with **Dept. of Veteran Affairs** for a collaborative project with (a) "Exoskeleton" and (b) finalizing agreement to have veterans test and evaluate NASA's RoboGlove in the Palo Alto and Cleveland clinics from our Human Robotics Systems Program
- Collaboration with **ARPA-e/Dept. of Energy** in new battery chemistries to aide in battery tech development



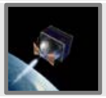





STMD Partners with Universities to Solve The Nation’s Challenges

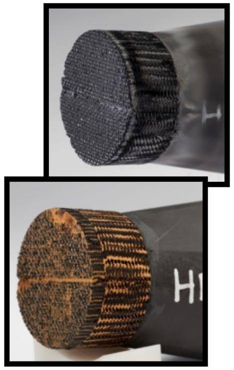
U.S. Universities have been *very* successful in responding to STMD’s competitive solicitations

- STMD-funded university space technology research spans the entire roadmap space
- More than 120 U.S. universities have led (*or are STTR partners on*) more than 450 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 	223	223	• Early Career Faculty • Early Stage Innovations • NASA Space Technology Research Fellowships ***Annually***
NIAC 	76	21	• NIAC Phase I • NIAC Phase II ***Annually***
Game Changing Technology Dev 	32	10	• Various topics released as Appendices to SpaceTech-REDDI ***Annually***
Small Spacecraft Technology 	22	13	• Smallsat Technology Partnerships Cooperative Agreement Notice every two years, with the next opportunity in 2015
Flight Opportunities 	114	46	• Announcement of Flight Opportunities - in the future, funded SAAs to U.S. universities, non-profits and industry to pay for flights on their own are planned. ***Twice Annually***
STTR 	*169*	*159 w/ univ partners*	• *Annual STTR solicitation*
Centennial Challenges 	*3 Challenges (1 Challenge university-run)*	*23 teams competed (4 univ-led)*	• *One or more challenges annually* • *Starting in FY14: challenge competitions with a **procurement track** to fund **university teams** via grants*

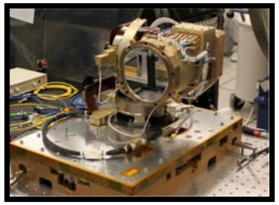
STMD-SMD Alignment Examples

- **Entry, Descent, & Landing**
  - MEDLI, MEDLI+ & Entry Systems Modeling – Mars EDL systems design
  - Woven TPS (HEEET) – Venus, Mars & Outer Planets
  - Low Density Supersonic Decelerator – Increased mass to Mars surface
  - Hypersonic Inflatable Aerodynamic Decelerator (HIAD) & Adaptable, Deployable Entry Placement Technology (ADEPT) – deployable heat shields for Venus and Mars provides much lower entry loads

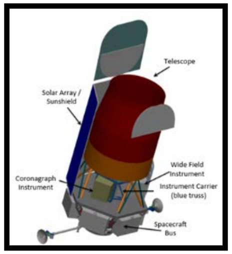


- **Propulsion & Power**
  - Green Propellant Infusion Mission (GPIM)- alternative to hydrazine
  - Solar Electric Propulsion (SEP) – enabling new science missions
  - Solar Sail – enables unique vantage points for heliophysics
  - Small Fission – power for outer planet missions

- **Communication & Navigation**
  - Deep Space Optical Comm. (DSOC) & Laser Communication Relay Demo (LCRD) – up to 10x data return for planetary and near-Earth missions
  - NICER/SEXTANT & Deep Space Atomic Clock (DSAC) – Highly accurate deep space navigation, higher duty cycle for DSN data return

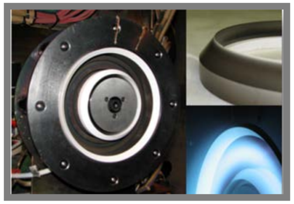


- **Instruments, Sensors, & Thermal**
  - High Performance Spaceflight Computing – broadly applicable to science missions
  - AFTA / WFIRST Coronagraph – to perform direct observations of exoplanets and determining their atmospheric content



STMD-HEOMD Alignment Examples

- **Solar Electric Propulsion (SEP)**
  - Enabling for ARM and humans to Mars
  - Technologies: Advanced Solar Arrays, High-Power Hall thrusters & PPUs

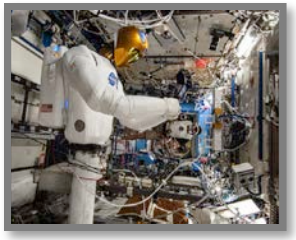


- **Life Support and Resource Utilization**
  - Mars Oxygen ISRU – testing on Mars 2020 and needed for humans to Mars
  - Next Gen. Life Support – Space suit components; Highly reliable closed loop air revitalization; Radiation dosimeter, modeling, forecasting and shielding

- **Mars Entry, Descent and Landing Technologies**
  - LDSD – allows up to 15 mt Mars landed mass
  - Woven TPS – potential use on Orion and later Mars entry system
  - HIAD & ADEPT – deployable entry systems for large heat shields

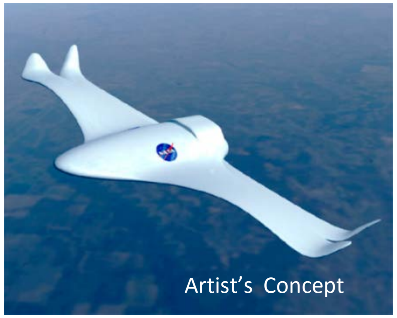
- **Space Launch System (SLS) Technologies**
  - CPST – long duration cryogenic storage for SLS upper-stage
  - Composite Tanks & Structures – upper-stage use to increase SLS payloads

- **Other Key Exploration Technologies**
  - Human Robotic Systems (R2, R3 & R5) – to reduce crew workload
  - Nuclear Fission systems for Mars surface power
  - Optical Communications (LCRD & DSOC) & Deep Space Navigation (DSAC)
  - Inflatable Air-Lock – to reduce structural mass



STMD-ARMD Synergies (FY14)

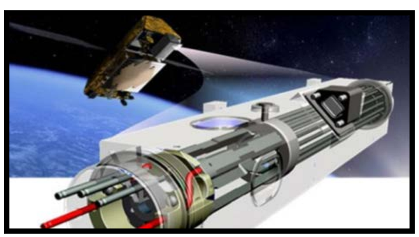
- **Aviation Safety**
  - External hazard sensors; pressure sensitive paint; wing tip vortex sensors
  - SBIR projects
- **Fundamental Aeronautics**
  - Advanced EDL - Computation (HEDL)
  - Parachutes under LDSD; Wings under Silent and Efficient Supersonic Bi-Directional Flying Wing
  - Advanced Manufacturing ; Nanotechnology ; Computational Materials ; Low mass cable harness structural health monitoring
  - Advanced composites/lightweight materials
  - SBIR projects
- **Airspace Systems:**
  - SBIR projects
- **Aeronautics Test Technologies:**
  - SBIR projects
- **Integrated System Research Project:**
  - UAS Challenge
  - SBIR projects


Artist's Concept

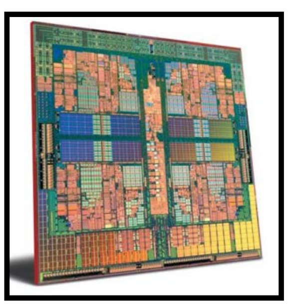
STMD- Aerospace Industry Alignment Examples

- **Structures and Materials**
  - Composite Tanks & Structures – for improved launch vehicle performance
  - HIAD – for orbital down mass capability

- **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



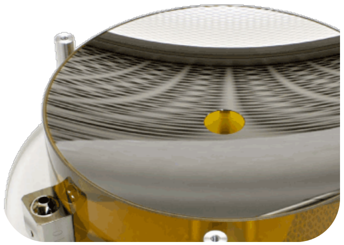
- **Communication & Navigation**
  - LCRD – replacing RF based gateway links with optical links and reduce RF spectrum utilization on commercial satellites
  - DSAC – improved timing for next generation GPS satellites

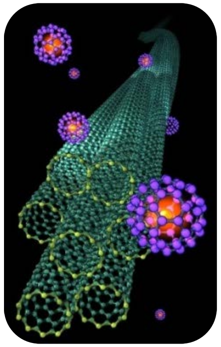


- **Instruments, Sensors, & Robotics**
  - High Performance Spaceflight Computing – for more capable radiation hard avionics for commercial communication satellites
  - Human Robotic Systems (R5) – to perform environmentally hazardous tasks and operate within terrestrial settings

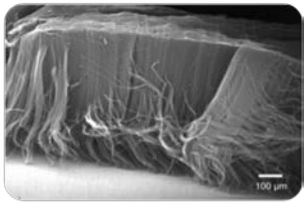
Space Technology Investments to Advance Future Capabilities

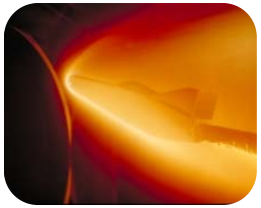
STMD continues to solicit the nation's best and brightest technologists across academia, industry, and government to drive innovative, enabling solutions in such areas as:





- **Solar Electric Propulsion** – Advanced high-power, low-volume solar arrays and high-power propulsion systems
- **Space Power-** Affordable, High Efficiency Power Generation and Energy Storage Systems
- **Life Support and Resource Utilization** - High Performance Resource Production and Recycling Systems
- **Entry, Descent, and Landing** - Advanced Computational Modeling and Analytical Simulation Tools
- **Space Robotic Systems** – High Reliability Sample Return Robots and low mass deep ice penetration systems
- **Space Optical Communications** – Enhanced Deep Space Optical Communication Capabilities for small space crafts and high efficiency laser systems
- **Lightweight Space Structures** – Ultralight, Ultrastrong Nanomaterials
- **Space Observatory Systems** – Advanced Optical Coating Materials for Space Environments





Summary: Space Technology Critical to our Future

- NASA's investments in Space Technology provide the transformative capabilities to enable new missions, stimulate the economy, contribute to the nation's global competitiveness and inspire the nation's next generation of scientists, engineers and explorers.

- Over the past three years, Space Technology has made significant progress on a wide array of new capabilities and technologies. We are delivering what we promised: new technologies and capabilities. FY15 demos or major tests for Small Spacecraft, Green Propellant, Deep Space Atomic Clock, and LDSD.

- Space Technology will continue to engage U.S. universities and academic institutions to develop and demonstrate technologies with more than 400 activities to date, including: fellowships, direct competitive awards of grants and contracts, and partnerships with NASA centers and commercial contractors.

- This budget request supports an accelerated development of a Solar Electric Propulsion (SEP) demonstration effort within Technology Demonstration Missions. SEP is critical and enabling for NASA's robotic mission to an asteroid.
  - SEP technology advances are also essential for future commercial satellites and for deep space human exploration missions.

- With SLS and Orion coming online soon, the next great leaps in space exploration are within our grasp, but all of these leaps require significant and sustained investments in Space Technology beginning now.

BACKUPS