National Aeronautics and
Space Administration

Space Technology Mission Directorate

NAC Meeting

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Space Technology Mission Directorate

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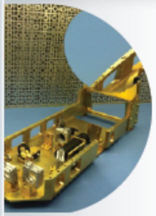
Deep Space Exploration is Near

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

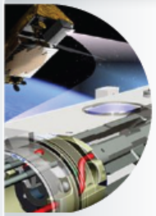
Permits more capable science missions, eventual human missions to mars including, hypersonic and supersonic aerodynamic decelerators, a new generation of compliant TPS materials, retro-propulsion technologies, instrumentation and modeling capabilities.

Space Robotic Systems

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

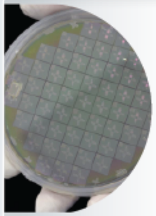
Lightweight Space Structures

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.



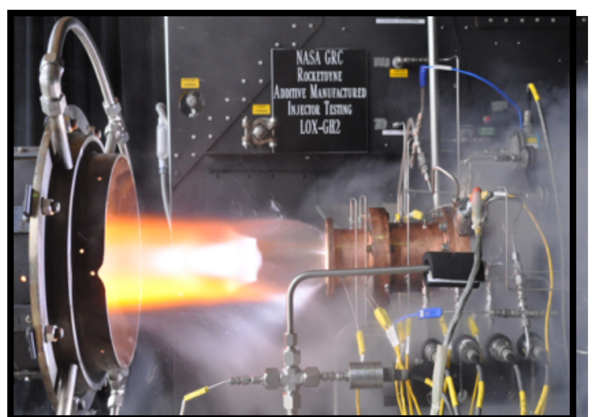
Space Observatory Systems

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

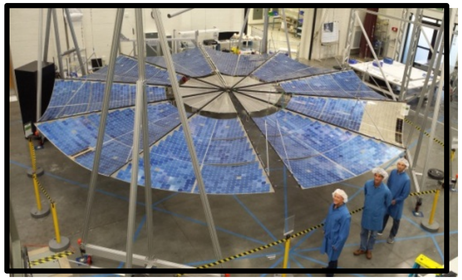
STMD Investments to Advance Future Capabilities of Space Launch System (SLS) & Orion

- 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

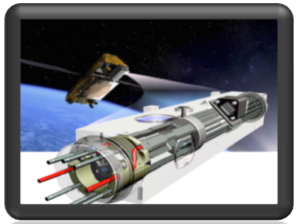
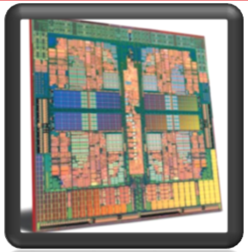
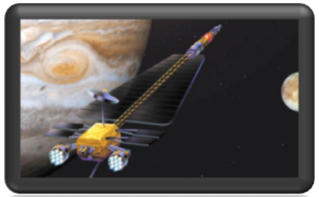
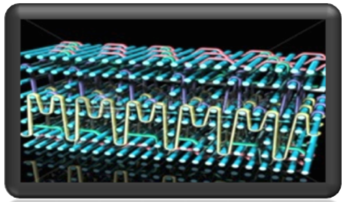


STMD Investments to Advance Human Exploration of Mars

- 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
- Supersonic Retropropulsion – technology for future large mass Mars landing and reusable launch vehicle
- Synthetic Biology - a synthetic biology-enabled membrane that can be used extensively in life support applications



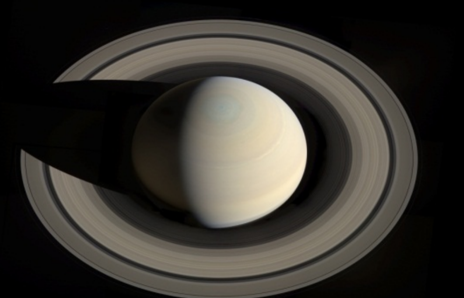
STMD Investments to Advance Outer Planetary Exploration

Discovery 2014
- *Maturing novel communication technology to provide order of magnitude higher data rates for deep space exploration*
- *Developing low-mass, high performing Thermal Protection System material for planetary entry missions*

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

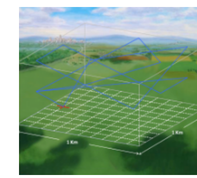
THE AEROSPACE CORPORATION
PUMPKIN INCORPORATED
tyvak NANO-SATELLITE SYSTEMS LLC
MSNW
BRM Bally Ribbon Mills
saft
APPLIED DEFENSE SOLUTIONS
BUSEK
AS AIRBORNE SYSTEMS
406 AEROSPACE
ILC DOVER
Micro Aerospace Solutions
L3
HONEYBEE ROBOTICS
Ball Aerospace & Technologies Corp.
AEROJET ROCKETDYNE
Honeywell
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
ADCOLE
POWERSAFE TECHNOLOGY CORPORATION
Masten
MIT Lincoln Laboratory
Microcosm Inc

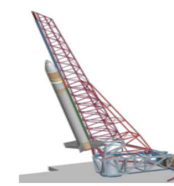
Collaborations with Other Government Agencies

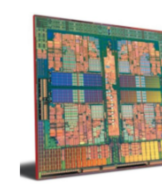
Currently, significant engagements include:

- Green Propellant Infusion Mission partnership with **Air Force Research Laboratory (AFRL)** propellant and rideshare with **DoD's Space Test Program (STP)**
- 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.
- 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 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** on use of Hosted Payload IDIQ contract mechanism for low cost access to space

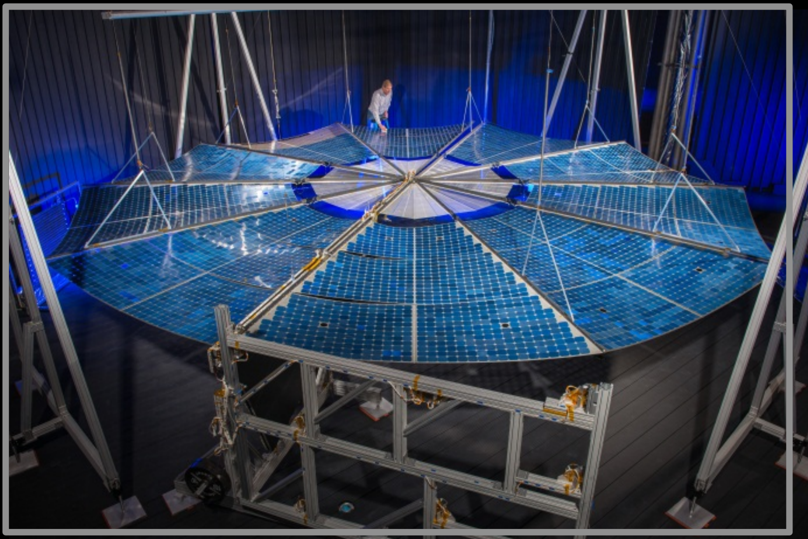
STMD has ***45 activities*** with ***43 other government agencies***, and ***10 activities*** with ***14 international organizations***. STMD is sharing rides for ***13 activities***.





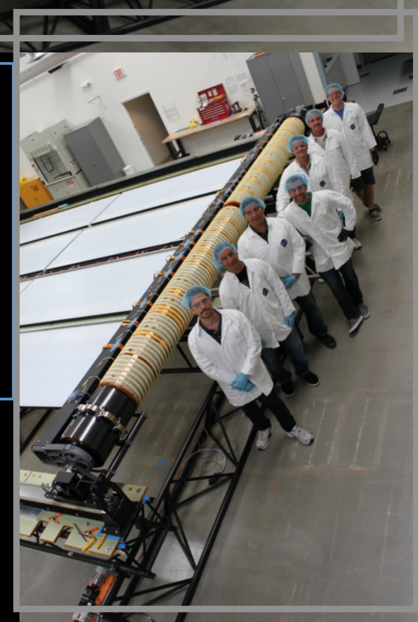


Test Success: High-Powered Solar Arrays



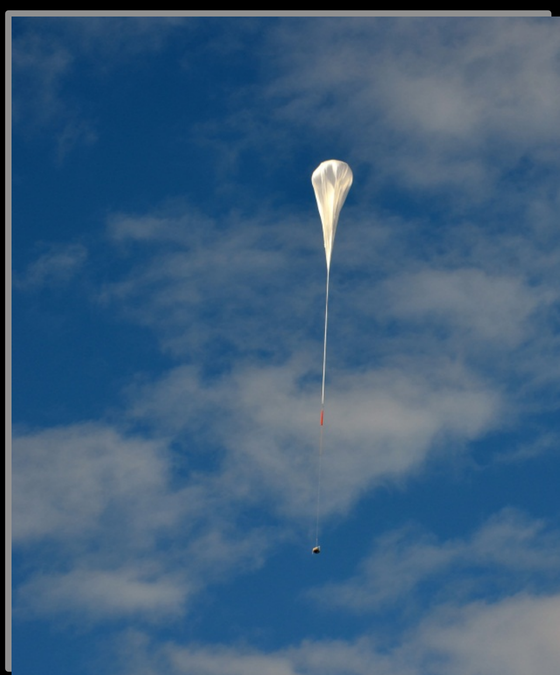
MegaFlex Engineering Development Unit (EDU) employs an innovative spar hinge to reduce stowed volume. Alliant Technical Systems (ATK)

ROSA Engineering Development Unit (EDU) employs an innovative stored strain energy deployment to reduce the number of mechanisms and parts. Deployable Space Systems (DSS)



Novel Solar Arrays sized for nominally 20kW/wing BOL
Brought to TRL 5+ by June 2014
Thermal vacuum deployments + dynamics & strength/stiffness & acoustic/vibration testing + validated models

Test Success:
Low Density Supersonic Decelerator

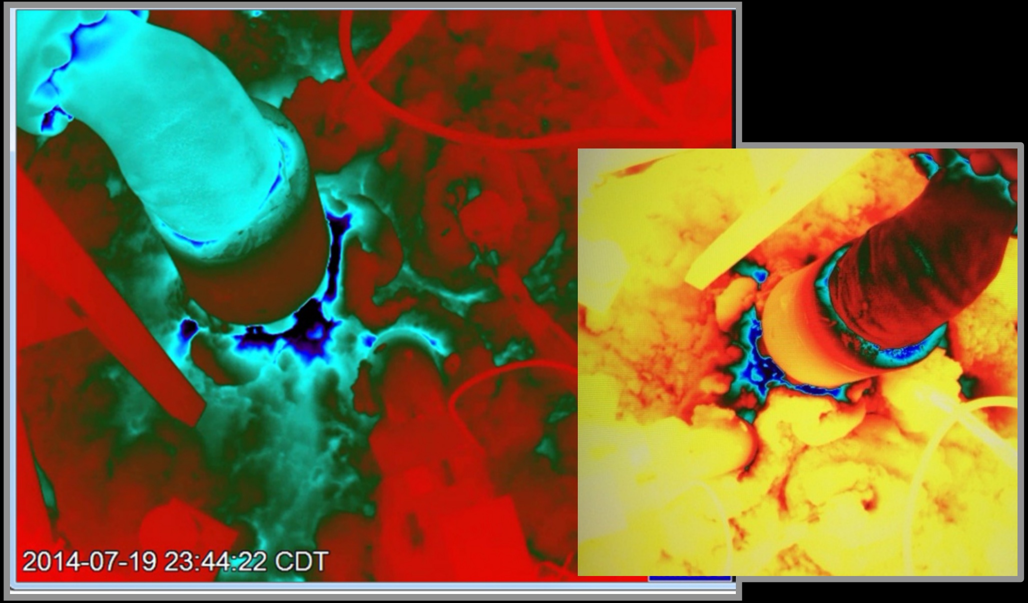


Successful LDSD flight test meeting all success criteria for the first flight

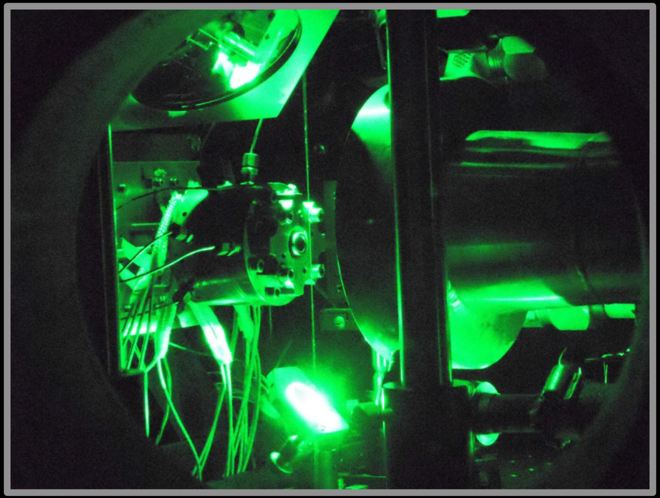
- Largest blunt body aeroshell ever flown supersonically
- Largest ballute ever successfully flown at supersonic conditions
- Largest supersonic parachute ever deployed
- Unprecedented quantity and quality of data collected

Test Success:
Composite Cryotank Technology Demonstration

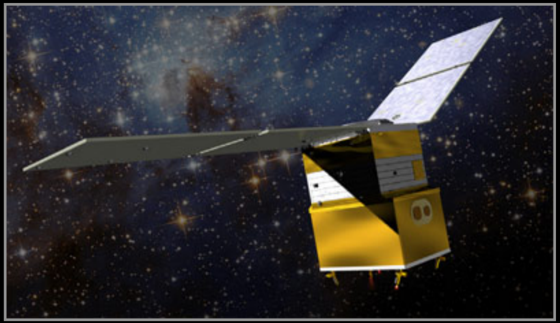
Successfully completed first cryogenic test on July 20. The tank was pressurized to approx. 60 psi at cryogenic conditions and the primary test objective of 5,000 micro strain was achieved.

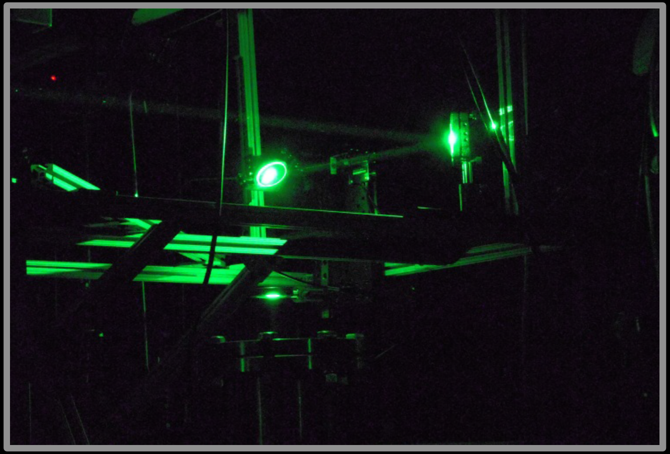


Test Success:
Green Propellant Infusion Mission



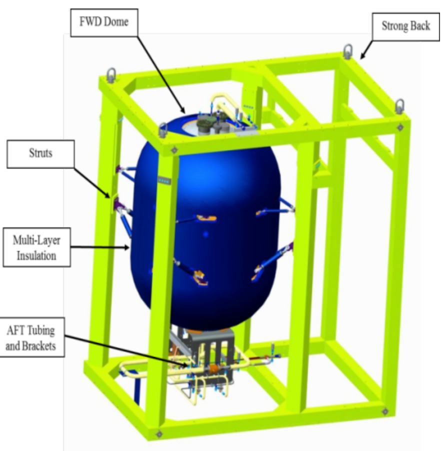
1N thruster plume chemistry using laser diagnostics



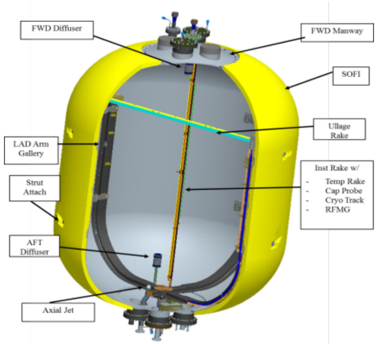


- The 1N Engineering Model thruster (flight thruster design) testing has completed with over 11,000 pulses. This testing demonstrates that the 1N thruster has the performance and capability to conduct the GPIM mission.
- The 22N Engineering Model thruster (flight thruster design) is progressing through manufacturing with the injector system and is on track for hot fire testing this year.

CPST Project Completes EDU Testing



EDU in Test Stand 300 at MSFC with key internal and external components noted



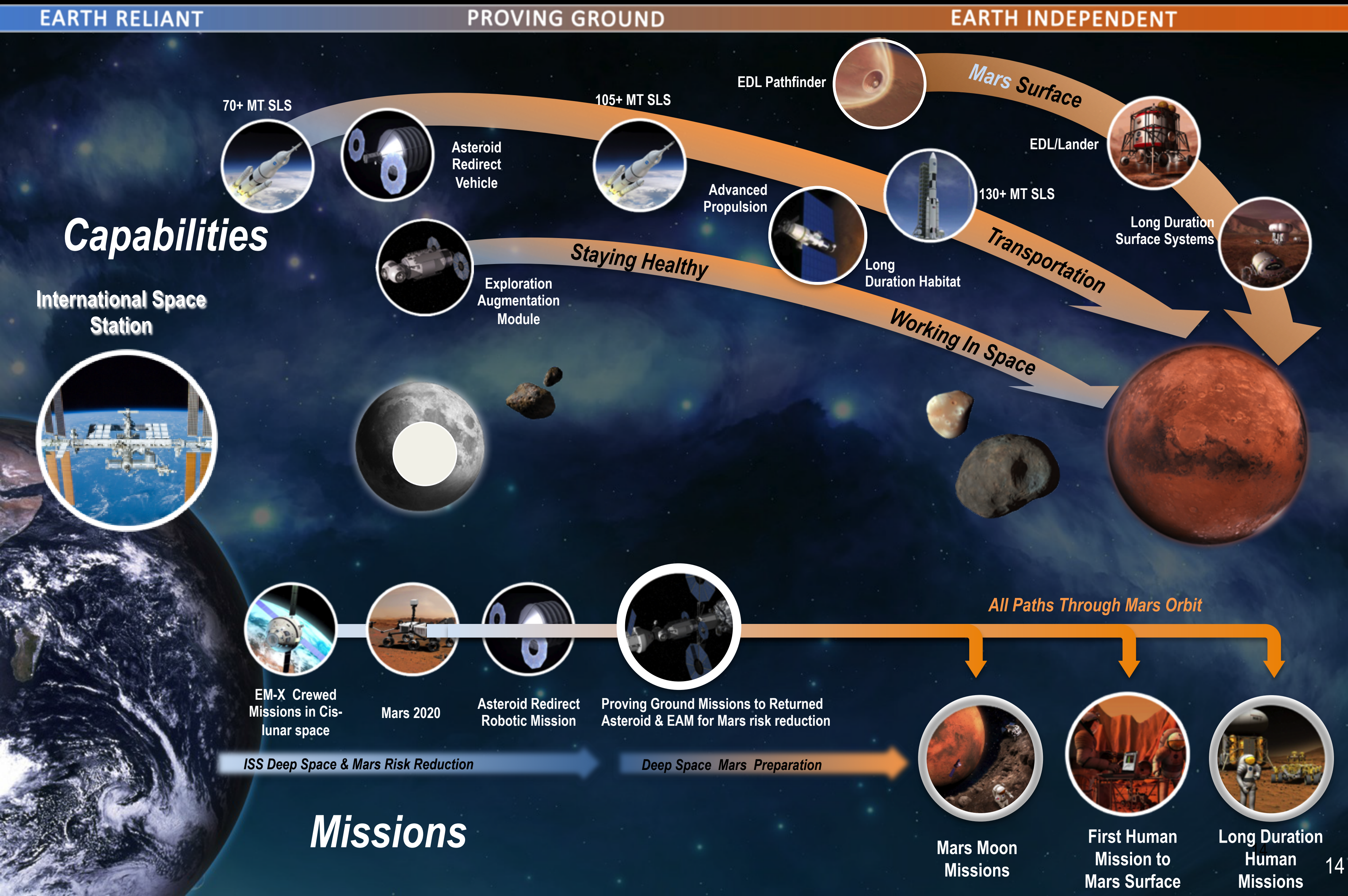
- Nine of ten test objectives were achieved
- Nine of fourteen stretch goals were reached
- EDU test data will be used to validate and/or anchor numerous CFM models

Model	Tool	Applicable Section of Test
Integrated Thermal Model	Thermal Desktop	From Tank Loading until TVS Performance Testing
Axial Jet and TVS Model	SINDA	During Axial Jet Operations (Ground Heat Load Measurement and On Orbit Heat Load Measurement)
LAD TVS Model	GFSSP	During LAD TVS Operations (On Orbit Heat Load measurement and LAD Outflow testing)
Tank Fill Model	GFSSP	During Tank Loading
Tank Boil Model	C3PO	During Tank Lockup periods (before vacuum, during initial vacuum pull, and heat Capacity Measurement)
Tank RF Mass Gauge Performance	FEM in Comsol	During Intervals of RF Mass Gauging
Cryo Tracker Performance Comparison	Hand Calcs	At all times of test where cryo is loaded
Purge Analysis	Hand Calculations	During Tank Loading

Evolvable Mars Campaign: Guiding Philosophy

- Leverages strong **linkage** to current investments in ISS, SLS, Orion, ARM, EAM, technology development investments, science investments
- Develops Earth independence for long-term human presence leading to the surface of Mars, starting in the Proving Ground, through the cis-lunar environment, enabling science along the way, and providing infrastructure for human exploration missions beyond Mars
- Accommodates a realistic budget, both in escalation and peaks coupled with a cadence of significant missions
- Starts off minimalist, grows as resources and capabilities permit
- Emphasizes prepositioning and reuse/repurposing of systems when it makes sense
- "Provides a basis for architecture development and identification and analysis of trade studies with our partners and stakeholders and incorporates the flexibility to adjust to changing priorities across the decades. From this work will emerge the roadmap we will follow through cis-lunar space to pioneer Mars." (from Pioneering Space paper)
- Not to develop "the plan" but develop different options to provide a range of capability needs to be used as guidelines for near term activities and investments

Evolvable Mars Campaign – Capability & Mission Extensibility



NRC Technology Recommendation

The exploration pathway is characterized by logical feed-forward of technical capabilities. … development programs should address the 10 capabilities below as a high priority, with a particular emphasis on the first three:

- **Mars Entry, Descent, and Landing (EDL)**
- **Radiation Safety**
- **In-Space Propulsion and Power (Fission Power, NEP, NTP, SEP, Cryogenic)**
- **Heavy Lift Launch Vehicles**
- **Planetary Ascent Propulsion**
- **Environmental Control and Life Support System (ECLSS)**
- **Habitats**
- **Extravehicular Activity (EVA) Suits**
- **Crew Health**
- **In-Situ Resource Utilization (ISRU) (using the Mars atmosphere)**

NRC Capability Assessments

NRC RECOMMENDED CAPABILITY	TECHNICAL CHALLENGES	CAPABILITY GAP	STMD Investments
Mars EDL	High - technologies needed for a Mars EDL system capable of handling very large payloads have yet to be identified.	High - payload capacity of the necessary EDL systems are currently far beyond the capability of existing EDL systems	Multi-speed regime, opportunistic approach: • Hypersonic & Supersonic inflatable Aerodynamic Decelerators • Propulsive Decelerators • Conformal & Woven Thermal Protection Systems • improved system models • MEDLI and Mars 2020 instrumentation
Radiation Protection	High - a suitable approach for providing adequate radiation safety has yet to be identified	High - the ability to provide the level of radiation safety required for a human mission to the Mars surface is so far beyond the state of the art	• Largely focused in HEOMD • STMD focus on developing prototype of integrated system to mitigate solar event risks through modeling and forecasting. Shift to GCR shielding analytical models
Fission Power (100KW)	Medium - extensive experience with reactor technologies, although some new technologies would be needed to provide reliable, long-term operation in space and on the surface of Mars.	Medium – despite past accomplishment in nuclear power technology in general and space nuclear power in particular, it has been almost 50 years since a U.S. space nuclear power program succeeded in conducting a flight test of a fission power reactor	• NTEC guidance to focus on 1-10 kW fission power system using Stirling conversion technology for in-space and planetary surface power generation • Finish 40kW non-nuclear system demonstration.
In-Space Cryogenic Propulsion	Medium – even though high-performance in-space cryogenic propulsion systems are already operational, new technologies are needed in-space fuel handling and long-term storage.	Medium - improvements needed to extend the in-space storage and operational lifetime of existing systems	• Cryogenic propellant management technologies including passive insulation, mass gauging and active cooling

NRC Capability Assessments

NRC RECOMMENDED CAPABILITY	TECHNICAL CHALLENGES	CAPABILITY GAP	STMD Investments
Nuclear Electric Propulsion	Medium - challenges associated with the fission power system	High - higher power levels required for the fission power and electric propulsion engines relative to the state of the art.	• Trade studies indicate that nuclear thermal propulsion is preferable approach at least in the near term
Nuclear Thermal Propulsion	Medium - the NERVA program developed most of the technologies that would be needed by an operational NTP system	Medium - the NERVA program tested a full-scale system, but the state of the art has degraded somewhat during the ensuing 40 years	Largely focus of HEOMD • ground testing technologies for nuclear thermal propulsion systems • system component technologies STMD focus on cryogenic propellant storage
Solar Electric Propulsion	Low - SEP systems are well developed with a long history of operation in space	High - the power level of state-of-the-art systems is so far below the power level needed for a crewed spacecraft transiting to and from Mars	Demonstrate a extendable 50kW system • High power solar arrays • High power, high thrust electric propulsion thrusters • Power processing & power management • Xenon storage tanks
SLS Heavy Lift Launch Vehicle	Low - no technological breakthroughs are required to complete SLS development	Low - designed to avoid the need either for new technologies or for substantial improvements to existing technologies	• Large-scale, low-cost lightweight composite structure demonstration • Cryogenic Propellant Management technologies • Cryogenic Composite Propellant Tanks

NRC Capability Assessments

NRC RECOMMENDED CAPABILITY	TECHNICAL CHALLENGES	CAPABILITY GAP	STMD Investments
Planetary Ascent Propulsion	Medium - past experience with lunar ascent engines and existing in-space propulsion systems provide a solid foundation for developing the technologies needed for Mars	Medium - improvements are needed to advance available technologies enough to provide the power needed ascent from Mars	• Early-stage work in hot gas TVC For planetary ascent vehicle, and single-Stage-to-Orbit Mars ascent vehicle engine
ECLSS	Medium - ECLSS technologies and systems are already operational	High – substantial improvements are needed to extend the lifetime and increase the reliability of existing technologies and systems	• Focused approach in partnership with HEOMD to develop closed loop air revitalization and water recovery • Delivery of water technologies to HEOMD, now shifting to focus on closing the air loop
Habitats	Medium - NASA has extensive experience in designing and building habitats in LEO, culminating with the ISS	Medium – substantial improvements are needed to extend the lifetime and increase the reliability of existing technologies and systems and to assure that habitat systems work as expected in the partial gravity of the Moon and/or Mars	Inflatable habitats main focus in in HEOMD. STMD focus is in component level and conceptual work • ultralight flexible shielding film for extreme heat and radiation • expandable/foldable structures for habitats • self-deploying, composite habitats • inflatable airlock designs • Integrated advanced habitat design
EVA Suits	Low - substantial research and experience with EVA suits in space and, to a lesser extent, on the surface of the Moon	Medium – advances are needed to accommodate the long duration of a human mission to the Mars surface during transit and on the surface	• Delivering rapid cycle amine system and variable oxygen regulator system to HEOMD. • Delivering high-performance EVA glove • Continued work on high energy density batteries

NRC Capability Assessments

NRC RECOMMENDED CAPABILITY	TECHNICAL CHALLENGES	CAPABILITY GAP	STMD Investments
Crew Health	Medium - final solutions to many physiological and psychosocial threats to crew health have yet to be identified	Medium - solutions to some issues are rather well defined, but others still require substantial research	Focus of HEOMD, STMD focus is in largely low-TRL work: • rapid electrochemical detection and identification of microbiological and chemical contaminants for manned spaceflight • microfluidic extraction of DNA for Identification of unknown organisms in microgravity • multi-modal neuro-diagnostic tool for exploration missions • microfluidic label-free sensing for rapid multiplexed pathogen detection in space
ISRU Mars Atmosphere	Low - technologies to achieve the ISRU capabilities described above have been demonstrated on Earth	High - there is a large gap between the capabilities of the small-scale experiments completed to date and the development of a full-scale operational system capable of reliable operation during long-term exposure to the partial gravity, dust, atmosphere, and radiation environment found on the surface of Mars	• Partnered with HEOMD and SMD for robust system for oxygen production from Lunar and Martian Resources including a Technology demonstration of ISRU system on Mars 2020

Number of STMD Technology Projects Supporting Human Space Exploration at Each TRL

	Technology Readiness Level								
	1	2	3	4	5	6	7	8	9
Mars EDL	8	15	11	2	2	1	1		
Radiation Protection	4	7	2						
Fission Power (100KW)		2	2	1		1			
In-Space Cryogenic Propulsion	2	16	11	2	1	1			
Nuclear Electric Propulsion		4	3	1					
Nuclear Thermal Propulsion	6	2							
Solar Electric Propulsion		12	14	2	1		1		
SLS Heavy Lift Launch Vehicle	1	2			1				
Falcon Heavy Lift Launch Vehicle									
Planetary Ascent Propulsion		2	1						
ECLSS	10	9	5	2					
Habitats	3	6	4	4	3				
EVA Suits		7	3						
Crew Health	7	18	7	5					
ISRU (Mars Atmosphere)		1							
TOTAL:	41	103	63	19	8	3	2		

Technology Campaign

Sustained investment in NASA technology advances the agency's exploration capabilities and supports the innovation economy.

Theme: *Technology Drives Exploration*

Approach:

- Spotlight technology milestones, events and launches from June-September
- Include ancillary public engagements (Technology Days at the Centers) and a robust web and social media presence
- Work with other campaigns to ensure integration and transition

Campaign Launch: ***June 2014***

Resources:

- www.nasa.gov/technology campaign landing page
- www.communications.nasa.gov,Technology Toolkit
- https://twitter.com/NASA_Technology #321TechOff, Twitter
- www.facebook.com/NASATechnology #321TechOff, Facebook

National Aeronautics and
Space Administration

Technology Drives Exploration
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