National Aeronautics and
Space Administration

Technology & Innovation Committee

NASA Advisory Council

Presented by:
Dr. Bill Ballhaus, Chair

April 17, 2014

T&I Committee Meeting Presentations
April 15, 2014

- Space Technology Mission Directorate Update
  – Dr. Michael Gazarik, Associate Administrator, STMD
- Office of the Chief Engineer Overview and Discussion
  – Mr. Ralph Roe, NASA Chief Engineer
- Chief Technologist Introduction and Update
  – Dr. David Miller, NASA Chief Technologist, OCT
- Update on NASA Advanced Manufacturing Activities
  – Dr. LaNetra Tate, NASA Program Executive, Advanced Manufacturing, STMD
- Update on Small Spacecraft Technology Program
  – Mr. Andy Petro, NASA Program Executive, Small Spacecraft Technology Program, STMD
- Annual Ethics Briefing
  – Ms. Kathleen Teale, Staff Attorney, NASA OGC

T&I Committee Meeting Participants
April 15, 2014

- Dr. William Ballhaus, Chair
- Dr. Randall Correll, Consultant
- Mr. Gordon Eichhorst, Aperios Partners LLC
- Mr. Matt Mountain, Space Telescope Science Institute
- Mr. David Neyland, Draper Laboratory
- Dr. Mary Ellen Weber, Stellar Strategies, LLC

Absent:

Dr. Erik Antonsson, Northrop Grumman Aerospace Systems Corporation

Dr. Dava Newman, Professor, Dept. of Aeronautics and Astronautics at MIT

"The scope of the Committee includes all NASA programs that could benefit from technology, research and innovation."

Technology: A Definition

A solution that arises from applying the disciplines of engineering science to synthesize a device, process, or subsystem, to enable a specific capability.

Previous Recommendation for the NASA Advisory Council

Recommendation:

The Council recommends that NASA establish a basic research (engineering science) program relevant to its long-term needs and goals.

- The Council suggests that the Chief Technologist collaborate with the Chief Scientist and the Chief Engineer to establish formal guidance and seek funding for basic research in engineering science. The Council further suggests that NASA begin by managing the agency's basic research portfolio as a pilot activity that is funded separately from the Space Technology Program, similar to how OCT coordinates the agency's technology portfolio.

Major Reasons for the Recommendation:

The Council recognizes that the distinction has been established between basic research and technology. NASA's technology programs now have advocacy and, in the form of the Strategic Space Technology Investment Plan (SSTIP), strategic guidance. However, basic research (or engineering science) that may lead to the development of technology and engineering tools are no longer explicitly part of NASA's technology enterprise.

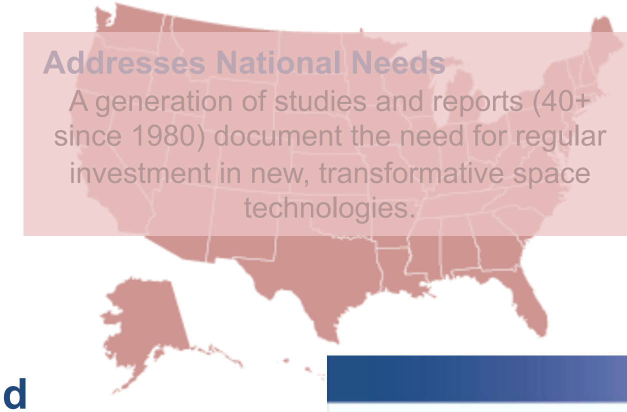
Consequences of No Action on the Recommendation:

Erosion of NASA's research and technology capabilities

Chief Engineer, Chief Scientist, Chief Technologist Vision for FES

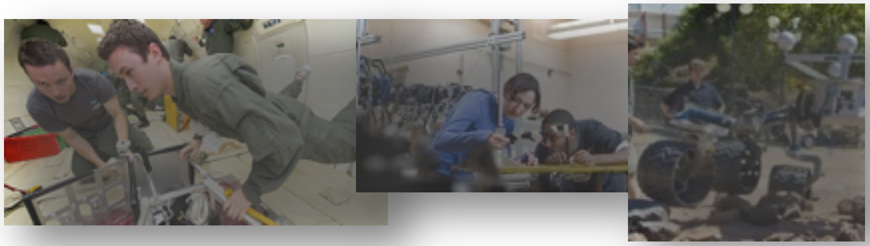
- Utilize the existing programmatic portfolio within the Space Technology Mission Directorate (STMD) to manage these new investments
- Evaluate and prioritize the input from the Engineering, Technology and Science Communities
- Partner with Industry, Academia and other Government Agencies
- Select a portfolio of pilot projects and begin to invest in Foundational Engineering Sciences for our future

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**



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

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.

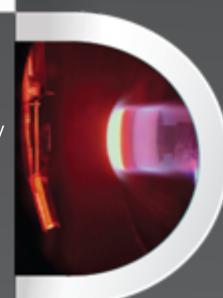
Game Changing Development seeks to identify and rapidly mature innovative/high impact capabilities and technologies that may lead to entirely new approaches for the Agency's broad array of future space missions.

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.



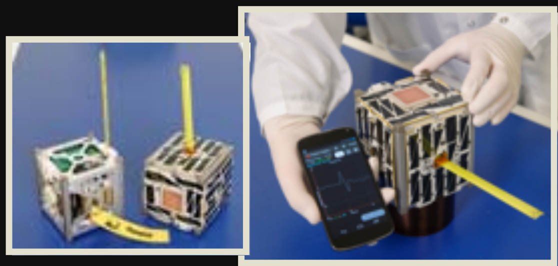
Creating Markets & Growing Innovation Economy

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.

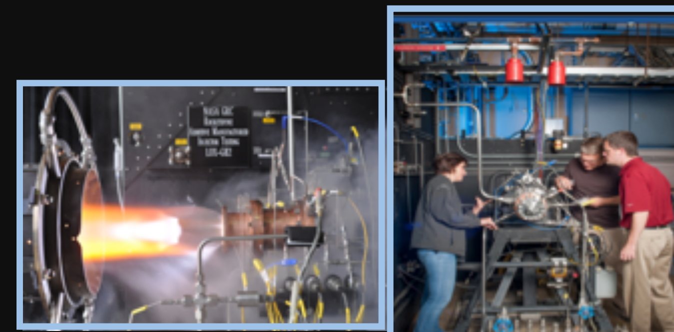
Flight Opportunities facilitates the progress of space technologies toward flight readiness status through testing in space-relevant environments. The program fosters development of the commercial reusable suborbital transportation industry.

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.

Major Highlights

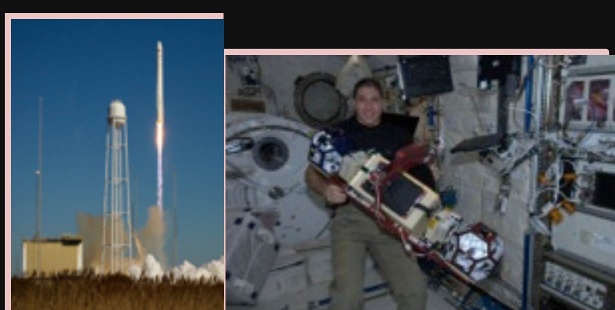


The PhoneSat 2.5 mission will be launched as a rideshare on SpaceX vehicle, to demonstrate command and control capability of operational satellites.

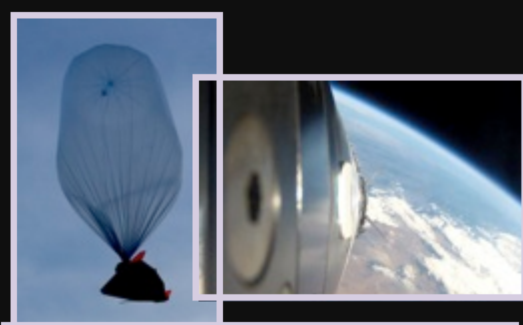


NASA engineers successfully hot-fire tested a 3-D printed rocket engine injector at NASA GRC, marking one of the first steps in using additive manufacturing for space travel.

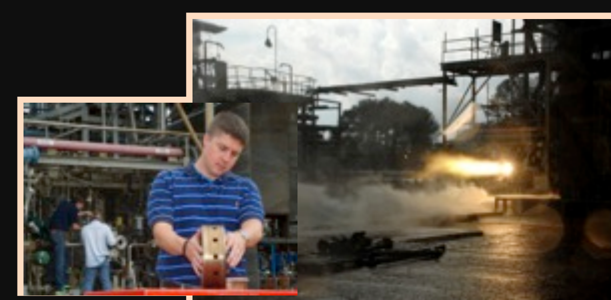
Successfully fabricated a 5.5-meter composite cryogenic propellant tank and testing at Boeing's facility in Washington and will continue testing at NASA MSFC this year.



ISS Fluid SLOSH experiment launched on Antares /Orb-1 on Dec. 18, 2013 and now aboard ISS for testing that will be used to improve our understanding of how liquids behave in microgravity

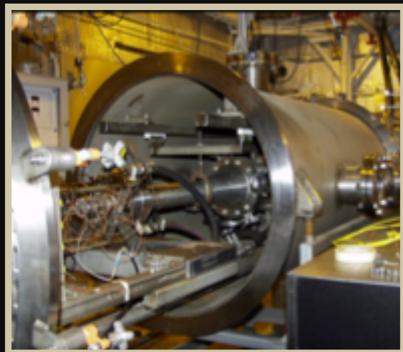


The Flight Opportunities program enabled flight validation of 35 technologies that were tested in space-like environments on four different flight platforms .



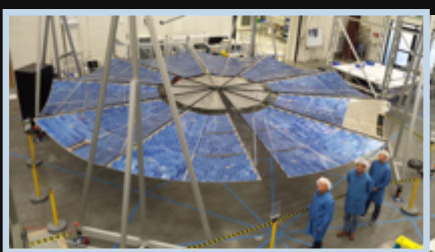
At NASA MSFC, the largest 3-D printed rocket engine injector NASA has ever tested blazed to life at an engine firing that generated a record 20,000 pounds of thrust.

Major Highlights

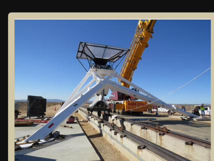


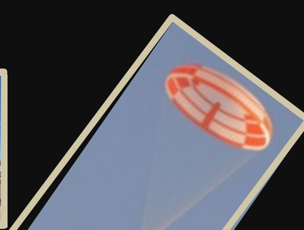
Green Propellant Infusion Mission took another step closer to infusion by proving capabilities for continuous thrust during testing and is preparing for flight test in 2015.

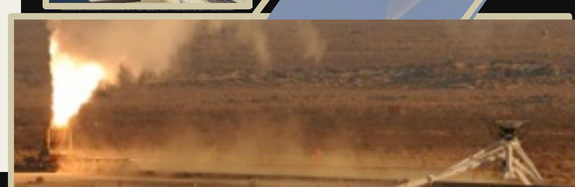
NASA's built and is sending a set of high-tech legs up to the ISS for Robonaut 2 (R2) that will provide R2 the mobility it needs to help with regular and repetitive tasks inside and outside the space station



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.

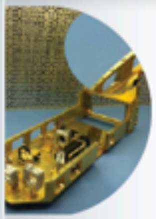
Surface Telerobotics- First real-time remote operations of a robotic rover from space and first simulation of human-robot waypoint mission

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.

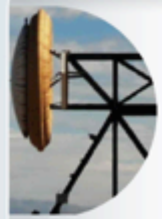


Space Optical Comm.

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

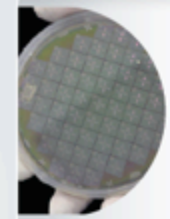
Creates future humanoid robotics, autonomy and remote operations technologies to substantially augments the capability of future human space flight missions.

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.

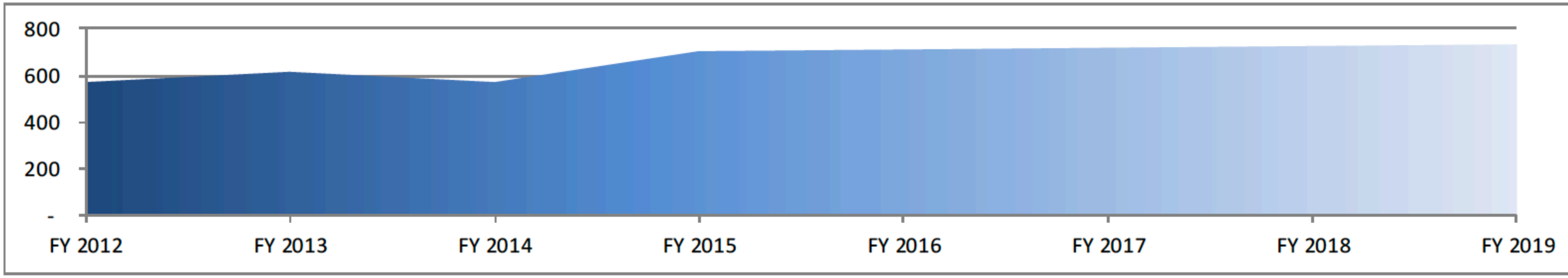


Space Observatory Systems

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

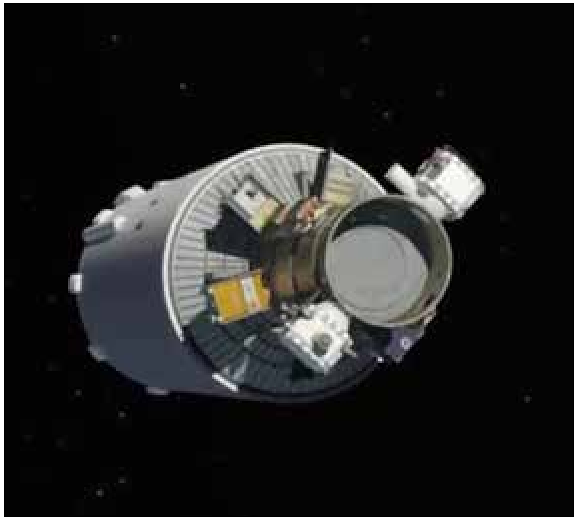
STMD FY2015 President's Budget

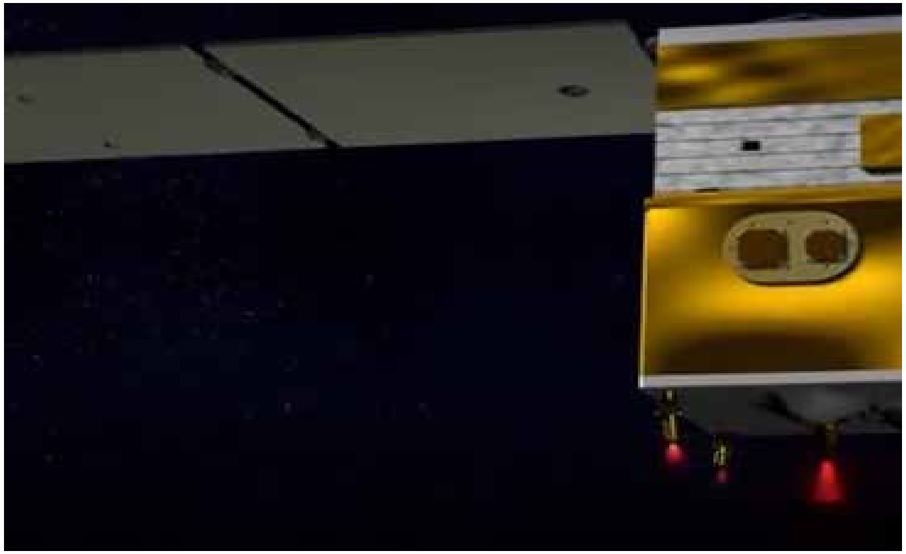


	Budget Authority ($M)		Notional			
		FY 2015	FY 2016	FY 2017	FY 2018	FY 2019
	FY 2015 President's Budget Request	**706**	**713**	**720**	**727**	**734**
OCT	Partnership Developments and Strategic Integration	**34**	**34**	**34**	**34**	**34**
Space Tech Mission Directorate	SBIR and STTR	**191**	**201**	**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

Technology Demonstration Mission - GPIM





"A high performance green propellant has the potential to revolutionize how we travel to, from and in space"

Michael Gazarik,

NASA Associate Administrator,

Space Technology Mission Directorate

GPIM Project Summary

- Project Description
  - Public/private partnership involving multiple government organizations and multiple contractors
  - Demonstrate advanced in-space propulsion system based on USAF developed AF-M315 "green" propellant
    - Over $15M of industry/government investment
    - More than a decade of research (handling, performance, etc.)
  - Mature technology to TRL9
  - Baseline mission:
    - Demonstrate ESPA class propulsion subsystem
    - Multiple orbit lowering operations/inclination change
- Project Status
  - Conducted CDR in March 2014
  - Component production and testing underway
  - Manifested Falcon Heavy STP-2 mission, August 2015

Why Green Propellant Matters

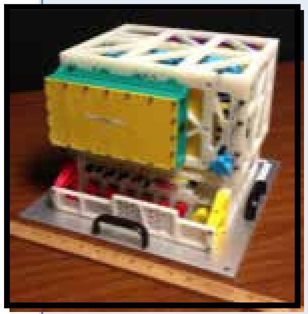
- Propellant Performance
  - ~50% higher density-specific impulse than hydrazine
  - Comparable system performance to bi-propellents
  - Lower temperature capability opens mission trade space
- Science
  - More payload capability or longer mission duration
  - Wide range of spacecraft sizes: large to nano
  - More launch options for benign secondary payloads without hazardous propellants
- Safety
  - Reduced toxicity enables easier handling and processing
  - Human Space Operations
- Economics
  - Reduced launch, range, and operations costs
  - US developed propellant and thrusters enable domestic sources
  - Supports “ship and shoot” concept of operations

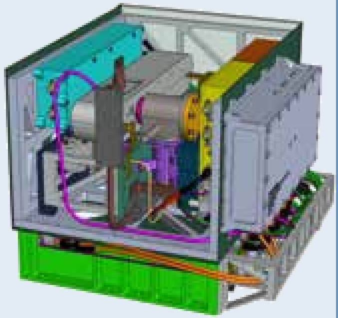
Aerojet Rocketdyne Technician handles AFM315E propellant

Traditional HAZMAT suit for fueling is not required

Flight proven green propellant system enhances U.S. industrial competitiveness

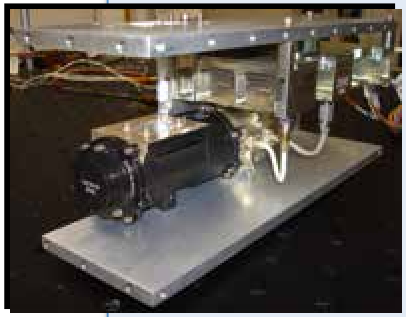
Technology Success: Deep Space Atomic Clock





Top Left; Rapid-prototype Model of DSAC
Top Right: DSAC Demo Unit Configuration.

Clock Breadboard Testing



Detector Subassembly Flight Article

Project Summary: *Develop a small, low-mass atomic clock based on mercury-ion trap technology providing unprecedented stability needed for the next-generation of deep space navigation and radio science.*

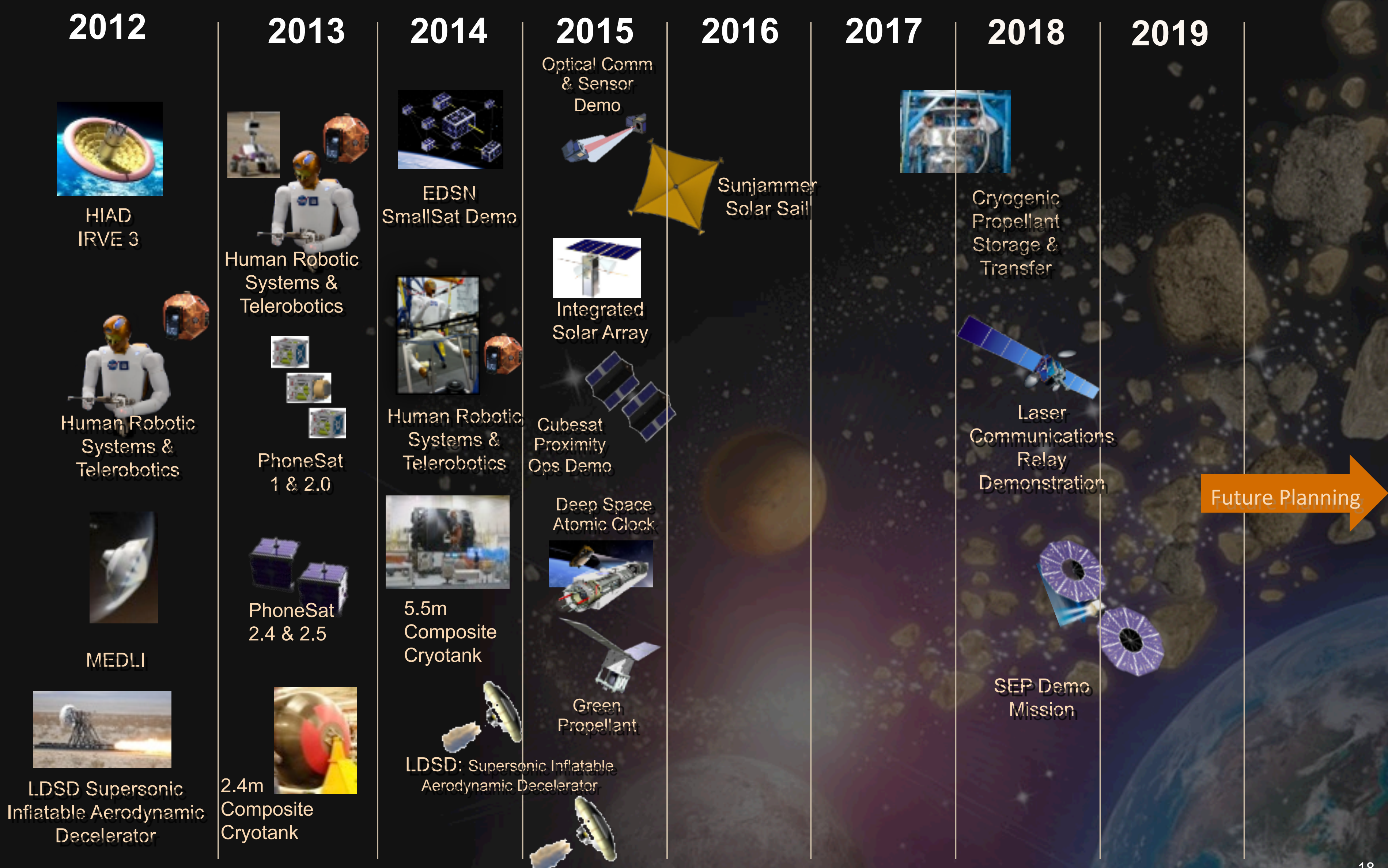
Accomplishments:

- The DSAC team have constructed two working breadboard (Payload Level and Clock Level)
- Low TRL issues (Lamp Bulb Manufacturing & Ion Tube Flight Design) have been resolved
- Secured a host mission for access to space
- Cultivated new infusion customers (NRO, Mil-Satcomm)
- Successfully conducted KDP-C

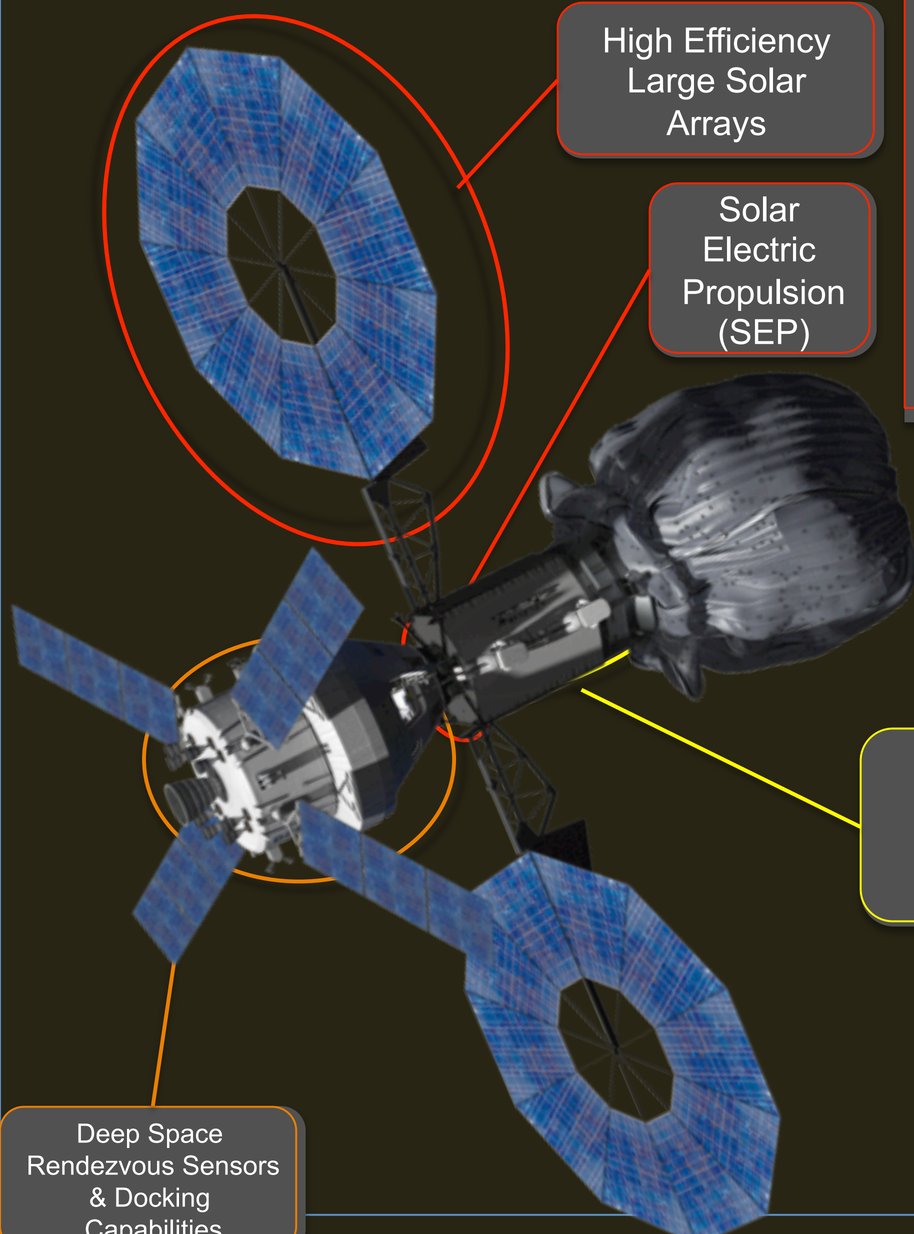
Plans:

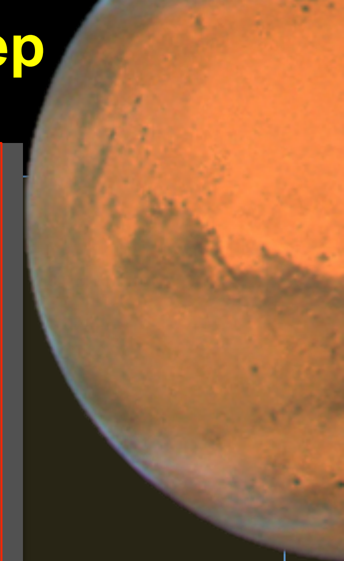
- Early I&T start with Ultra Stable Oscillator & GPS units
- Launch in 2015.

CY Major Events & Milestones



Asteroid Redirect Mission Provides Capabilities For Deep Space/Mars Missions





<u>In-space Power and Propulsion</u>:

- 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

<u>EVA</u>:

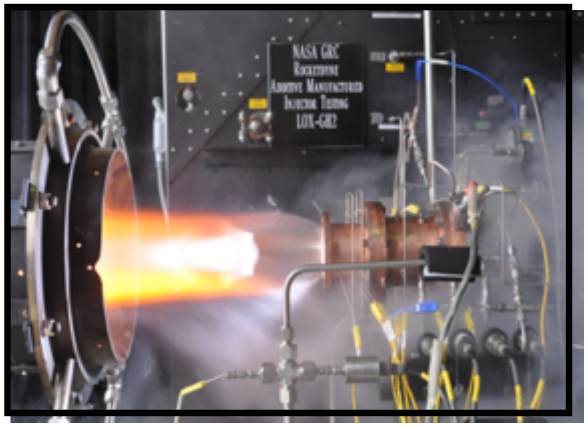
- Build capability for future exploration through Primary Life Support System Design which accommodates Mars
- Test sample collection and containment techniques including planetary protection
- Follow-on missions in DRO can provide more capable exploration suit and tools

<u>Crew Transportation and Operations:</u>

- 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.

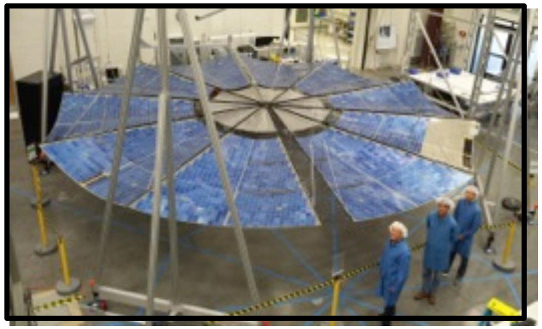
STMD Investments to Advance Future Capabilities of Space Launch System (SLS) & Orion

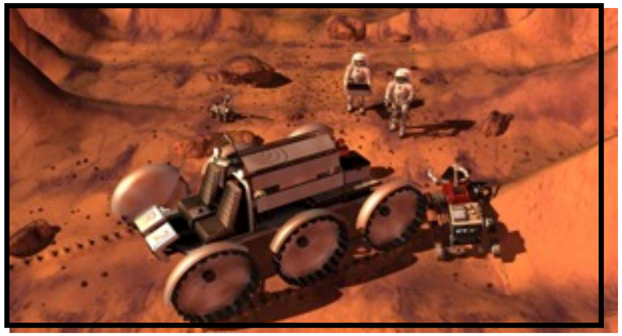
- Composite cryogenic propellant tanks and dry structures for SLS block upgrades
- Cryogenic propellant storage and transfer for upper stage block upgrades
- Additive manufacturing and testing of upper stage injectors, combustion chambers and nozzles
- Phase change material heat exchangers for Orion 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

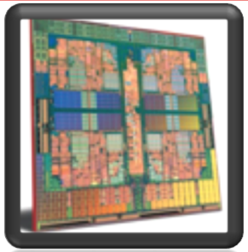
- High Powered SEP – cargo and logistics transportation to Mars
- CPST – either chemical or nuclear thermal in-space propulsion for crew transportation
- Composite cryogenic propellant tanks and dry structures – exploration upper stage
- Small Fission Power / Stirling Engine Power – Mars surface power
- 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

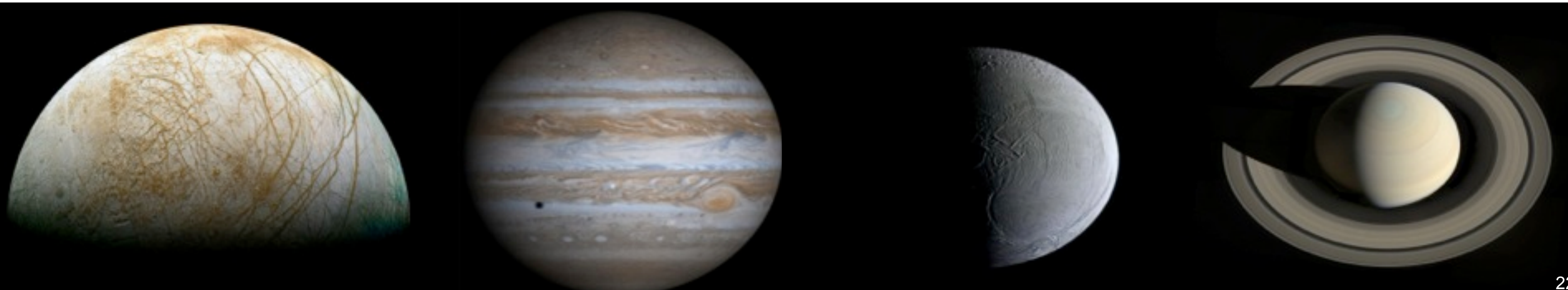




STMD is developing TPS and deep space communication technologies for infusion in SMD's Discovery 2014

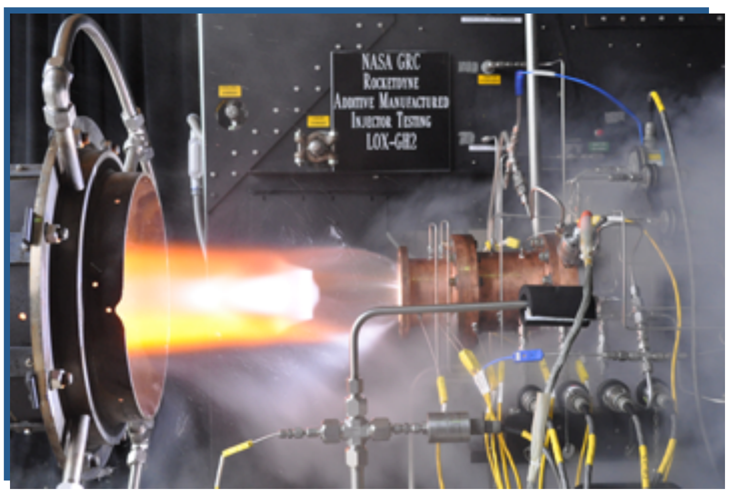
Technologies in FY15

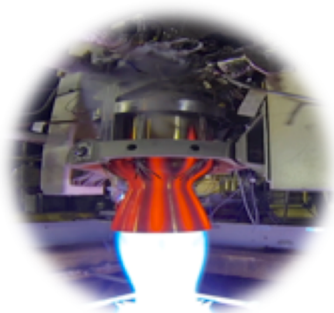
- Deep Space Optical Communications
- Deep Space Atomic Clock
- High Performance Space Computing
- Small Nuclear Fission / Sterling Power (kilo-power)
- Woven TPS for aerocapture and outer-planetary entry
- Europa Ice Penetration Challenge

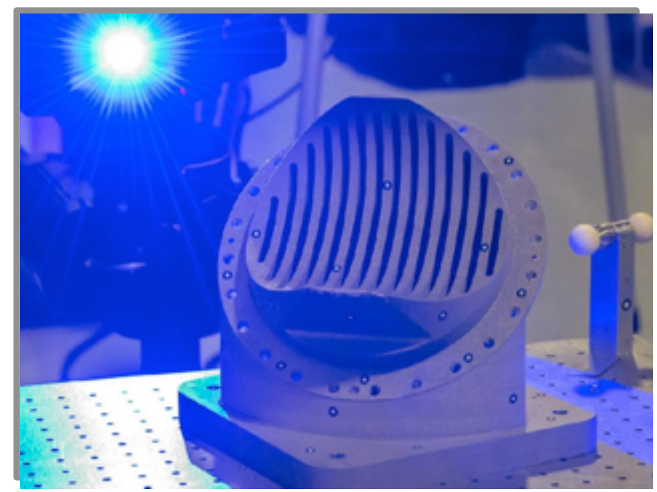


NASA Additive Manufacturing For Space

- NASA is partnering with industry to develop and test rocket engine parts
- Recent efforts done at NASA on rocket engine parts, additive can save months of fabrication and machining time and thousands of dollars. An injector part that typically takes six months to fabricate at a cost of more than $10,000 was fabricated in three weeks and cost less than $5,000.







Advanced Manufacturing is Critical to all NASA Mission Areas

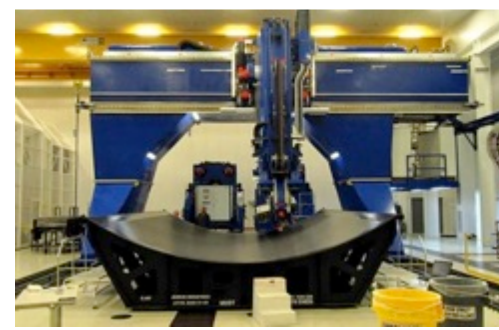
Promise of Additive Manufacturing

"Additive manufacturing will be a $5.2B industry by 2020" - *Terry Wohlers*

NASA Advanced Manufacturing Technology - Composites

- NASA's goal in large scale composite structures for Space is to develop low cost, lightweight, and thermally efficient structures, materials and manufacturing technologies for potential applications beneficial to the Space Launch System (SLS) launch vehicles.

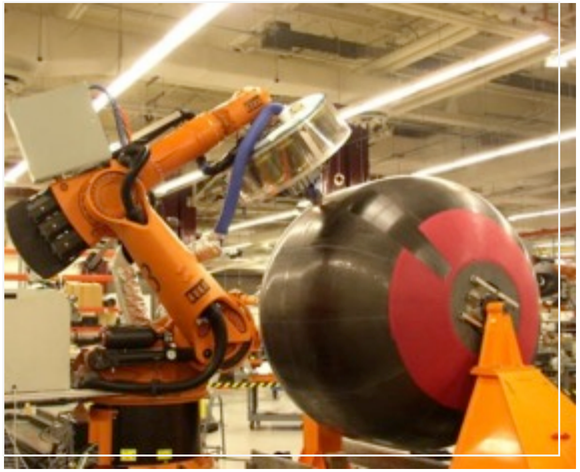
- NASA aims to gain better understanding of the entire trade space. Be a *smarter buyer* and a more effective, more relevant partner to the entire Aerospace Industry, in doing this we make smarter investments in advanced composite systems and leverage knowledge for future projects.



Advanced Manufacturing is Critical to all NASA Mission Areas

Development of Composite Cryogenic Tanks

2.4m



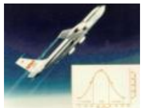
MSFC

5.5m

NASA In-space Manufacturing Technology Development Vision

International Space Station (ISS)

Parabolic



WE ARE HERE!

3D Print Tech Demo

Printable Electronics

Metal Printing

SmallSats

Add Mfctr. Facility

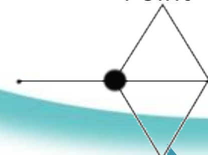
Optical Scanner

Recycler

Self-repair/ replicate

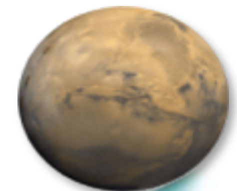
Asteroids

Lagrange Point



Lunar

Mars



Pre-2012

Ground & Parabolic centric:
- Multiple FDM Zero-G parabolic flights
- Trade/System Studies for Metals
- Ground-based Printable Electronics/ Spacecraft
- Verification & Certification Processes under development
- Materials Database
- Cubesat Design & Development

2014

- POC 3D Print: First Plastic Printer on ISS Tech Demo
- NIAC Contour Crafting
- NIAC Printable Spacecraft
- NIAC SpiderFab
- Small Sat in a Day
- NRC Study
- Center In-house work in additive, synbio, ISRU,robotics

2015

- Next Generation 3DPrint
- SmallSat in a Day ISS Demo
- Recycler Demo: : recycle plastic

2016 – 2017 – 2018

ISS: *Utilization/ Facility Focus*
- Integrated Facility Systems for Stronger types of extrusion materials for multiple uses including metals & various plastics
- Printable Electronics Tech Demo
- Smallsat Build & Deploy

2020-25

Lunar, Lagrange FabLabs
- Initial Robotic/ Remote Missions
- Provision some feedstock
- Evolve to utilizing in situ materials (natural resources, synthetic biology)
- Product: Ability to produce multiple spares, parts, tools, etc. "living off the land"
- Autonomous final milling to specification

2025

Planetary Surfaces Points Fab
- Transport vehicle and sites would need Fab capability
- Additive Construction

2030 - 40

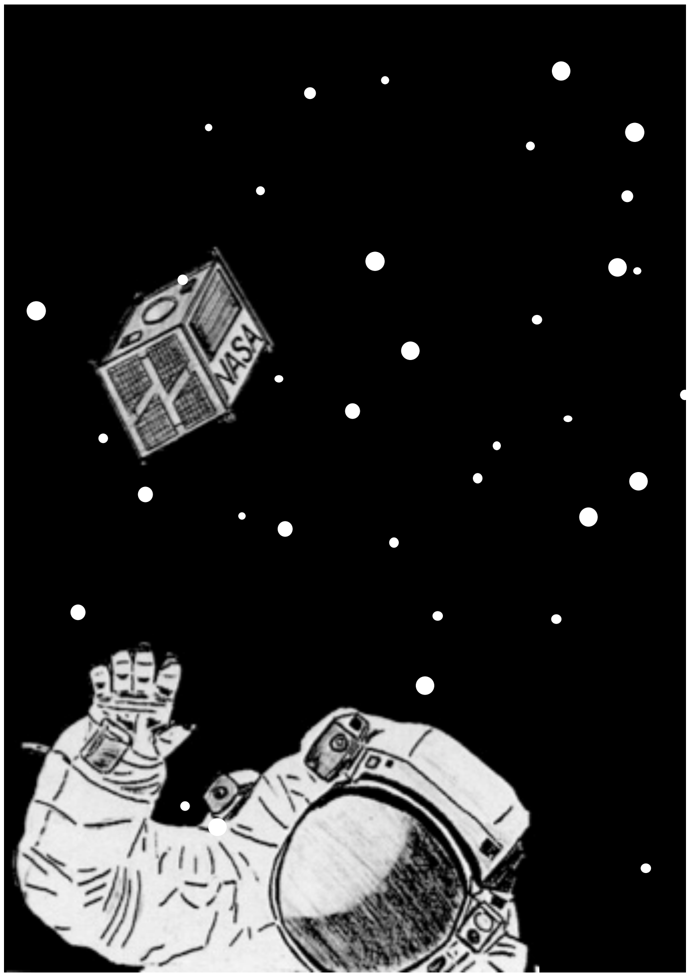
Mars Multi-Material Fab Lab
- Utilize in situ resources for feedstock
- Build various items from multiple types of materials (metal, plastic, composite, ceramic, etc.)
- Product: Fab Lab providing self-sustainment at remote destination

All dates and plans beyond 2014 are notional and do not imply planned investments

ISS Technology Demonstrations are Key in 'Bridging' Technology Development to Full Implementation of this Critical Exploration Technology. We believe this design is the right one for taking the very first step toward manufacturing in space!

Small Spacecraft Technology Program

Small, Affordable, Rapid, & Transformative Development and Demonstration



Combines previous Franklin and Edison Programs

Program Executive: Andrew Petro (HQ)

Level 2 Program Office at Ames Research Center

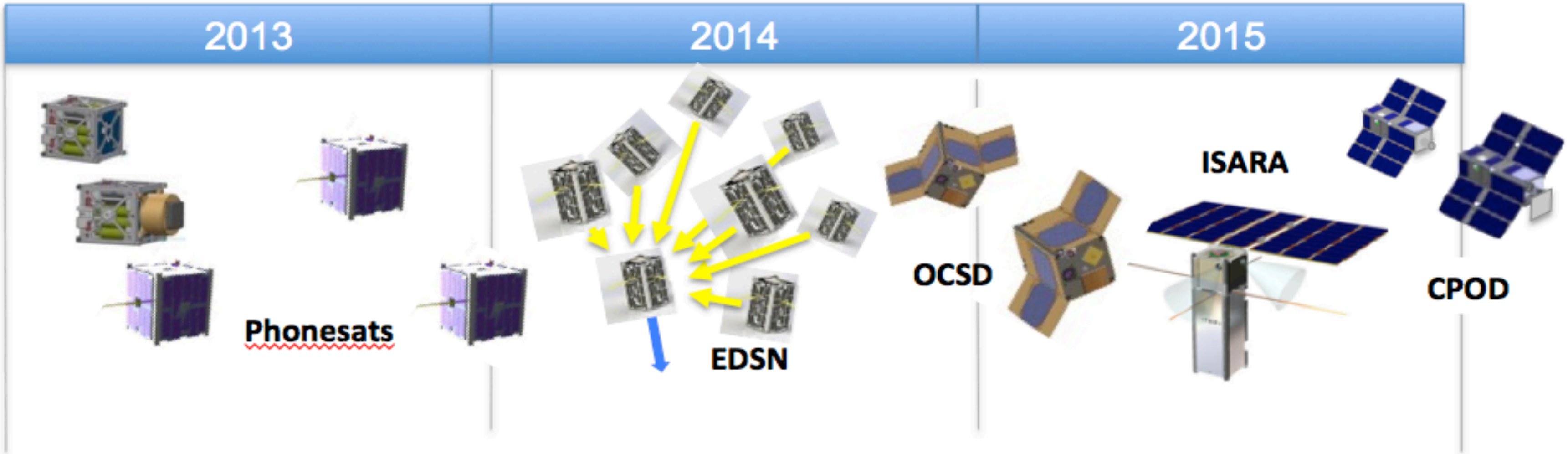
Program Manager: Bruce Yost

Objectives:

- Identify and develop new subsystem technologies to enhance or expand the capabilities of small spacecraft. **TRL 3 to 5**
- Demonstrate new technologies, capabilities, and applications for small spacecraft. **TRL 5 to 7**
- Use small spacecraft as low-cost platforms for testing technologies and capabilities with applications for spacecraft and systems of any size.
- Promote the small spacecraft approach as a paradigm shift for NASA and the larger space community.

Small Spacecraft Technology

Flight Demonstration Projects



Phonesat
Demonstrating use of a smartphone as the spacecraft control and data handling system - yielding extremely low cost satellites for many uses.

Led by NASA Ames Research Center

Launches: April 2013
Nov 2013
April 2014

EDSN (Edison Demonstration of Smallsat Networks
Demonstrating a small spacecraft swarm (8 cubesats) operating as a network for distributed sensors and communication

Led by NASA Ames Research Center

Launch: Fall 2014

OCSD (Optical Communication & Sensor Demonstration)
Demonstrating space-to-ground laser communications, low-cost navigation sensors, and proximity operations with two 1.5U cubesats

Led by Aerospace Corp.

Launch: 2015

ISARA (Integrated Solar Array and Reflectarray Antenna)
Demonstrating increased bandwidth for Ka-band radio communications by using the back of a deployed solar array as a radio antenna reflector

Led by JPL with Pumpkin, Inc.

Launch: 2015

CPOD (Cubesat Proximity Operations Demonstration)
Proximity operations and docking demonstration with two 3U cubesats

Led by Tyvak, LLC

Launch: 2015

Phonesat 2.5

T&I Committee Finding and Recommendation for STMD AA

Recommendation:

- The T&I Committee recommends that STMD characterize the small spacecraft mission market pull.
  - Civil, military, intelligence, commercial, academia
  - What is the technology's potential utility and societal benefits?
- Identify what is NASA's particular role in developing capabilities for this market. How can NASA "move the needle"?

Major Reasons for the Recommendation:

- There may be real potential in developing capability to improve space mission effectiveness by using small satellites.
- The market pull associated with small satellites has not been well characterized for the NAC T&I Committee.

Consequences of No Action on the Recommendation:

Erosion of NASA's science and technical capabilities

T&I Committee Finding for the NAC

Committee believes it is important for STMD to maintain a balanced space technology portfolio across all of the TRL-levels in the coming budget deliberations.

T&I Committee Recommendation for the NAC

Recommendation:

The Council recommends that the STMD AA & SMD AA collaborate to investigate whether policies and procedures should be modified to encourage the infusion of new technologies in small to medium class missions. The T&I Committee requests a briefing on the results of the investigation by the next meeting.

Major Reasons for the Recommendation:

- In highly competitive program solicitations, such as Discovery and Explorer, there is a disincentive to propose new technology because of the perceived risk.
- As a result, NASA may be missing an opportunity to leverage scientifically beneficial technology through small and medium science missions. In the long-term, this could erode NASA's scientific and technical capabilities.
- If the Agency wants to encourage and infuse appropriate new technologies in its small and medium class missions, it must develop a policy that incentivizes the inclusion of these technologies in the solicitation release.

Consequences of No Action on the Recommendation:

Erosion of NASA's science and technical capabilities