Technology, Innovation & Engineering Committee Report
NASA Advisory Council

Mr. Jim Free | May 30, 2019

TI&E Committee Scope

"The scope of the Committee includes all NASA programs focused on technology research and innovation."

–NASA Advisory Council Technology & Innovation Committee Terms of Reference, signed 6/28/12

TI&E Committee Meeting Attendees: April 30, 2019

- Mr. Jim Free, Peerless Technologies
- Dr. Kathleen C. Howell, Purdue University
- Mr. Michael Johns, Southern Research Institute
- Mr. David Neyland
- Dr. Mary Ellen Weber, Stellar Strategies, LLC *(online)*

TI&E Committee Meeting Presentations: April 30, 2019

- Space Technology Mission Directorate (STMD) Update and FY20 Budget Discussion
  - Mr. Jim Reuter, Associate Administrator (Acting), STMD
- Restore-L and IRMA: Dragonfly update
  - Mr. Ben Reed, Deputy Director, Satellite Servicing Projects Division
- Office of the Chief Technologist Update
  - Dr. Douglas Terrier, Chief Technologist
- Annual Ethics Training
  - Ms. Kathleen Teale, Attorney, NASA Office of the General Counsel
- Nuclear Thermal Propulsion Update
  - Mr. Sonny Mitchell, Project Manager, Nuclear Thermal Propulsion
- Office of the Chief Engineer Update
  - Mr. Joe Pellicciotti, NASA Acting Deputy Chief Engineer

National Aeronautics and
Space Administration

EXPLORE SPACE TECH

FY 2020 Exploration Technology Budget Update

NAC TI&E Committee Meeting

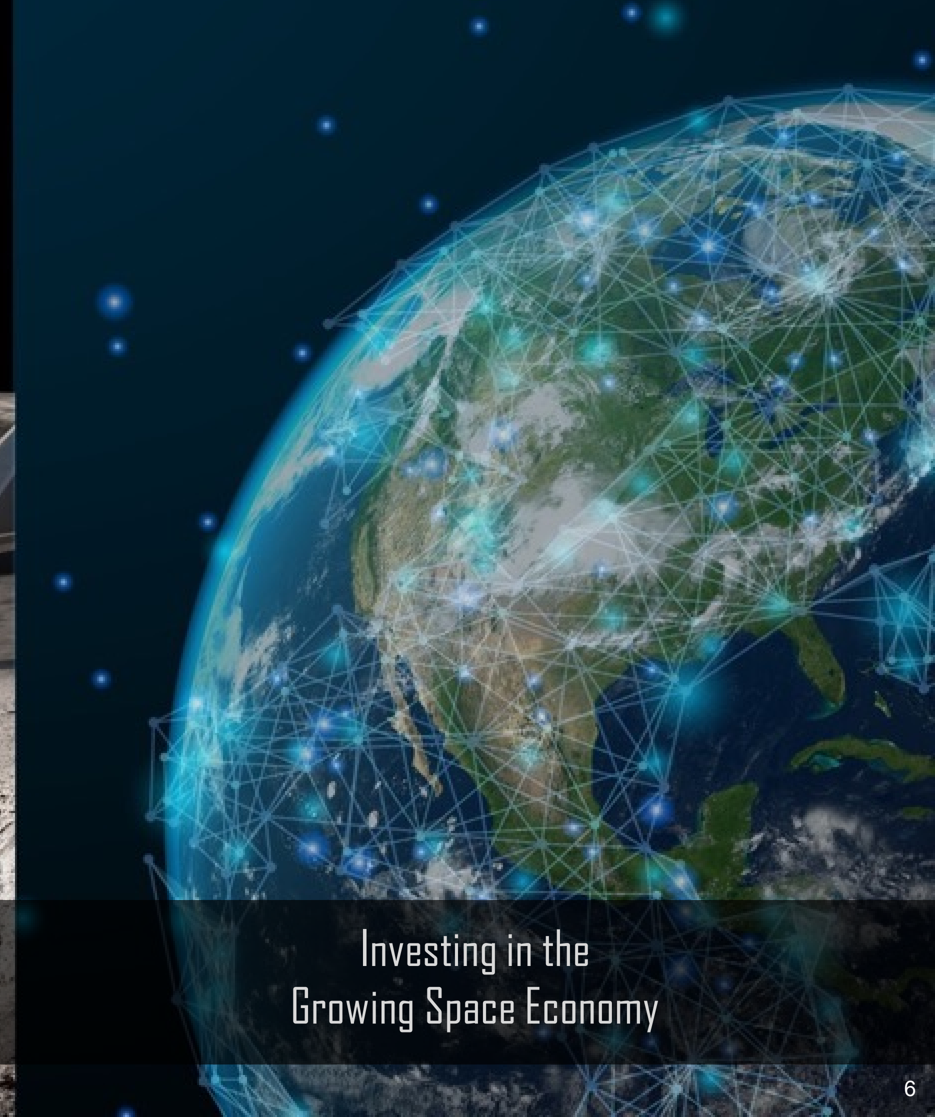
Mr. James Reuter, Associate Administrator (Acting) for NASA STMD | April 2019

Exploration Technology Strategic Investments

Exploration

Emphasis on the Moon
Keeping an Eye Towards Mars and Beyond

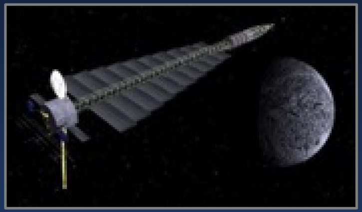
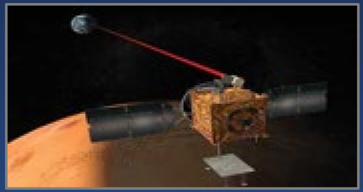
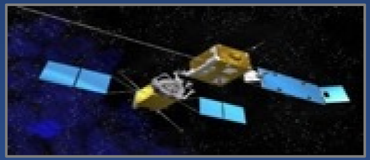
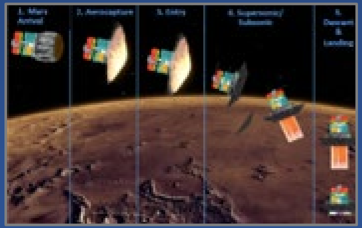
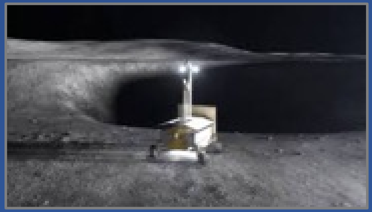
Commerce



Investing in the
Growing Space Economy

Key Technology Focus Areas

- ❖ Advanced environmental control and life support systems and In-Situ Resource Utilization
- ❖ Power and propulsion technologies
- ❖ Advanced communications, navigation and avionics
- ❖ In-space manufacturing and on-orbit assembly
- ❖ Advanced materials
- ❖ Entry, Descent and Landing
- ❖ Autonomous operations

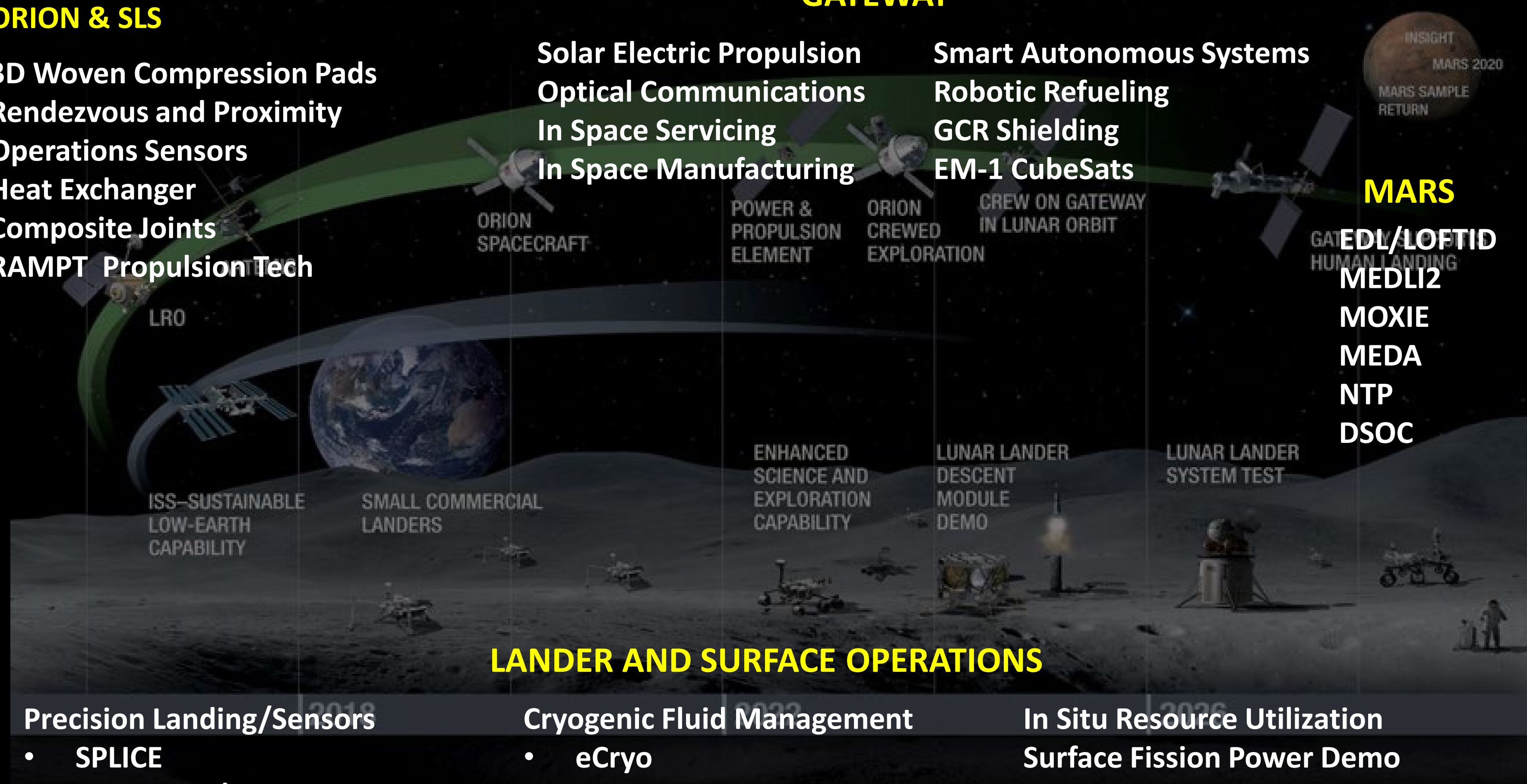
Exploration Technology FY 2020 Budget Request

Budget Authority ($M)	FY 2018 actuals	FY 2019 Appropriation	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Early Stage Innovation and Partnerships	**$91.9**		**$123.4**	**$118.0**	**$123.0**	**$118.0**	**$123.0**
Agency Technology and Innovation	$8.8		$9.4	$9.4	$9.4	$9.4	$9.4
Early Stage Innovation (NIAC, STRG, CIF/ECI)	$57.3		$77.4	$83.4	$83.4	$83.4	$83.4
Partnerships and Technology Transfer (CC, P&C, Tech Transfer, iTech)	$25.9		$36.7	$25.2	$30.2	$25.2	$30.2
Technology Maturation	**$151.5**		**$282.5**	**$227.2**	**$250.3**	**$246.7**	**$328.0**
Game Changing Development			$146.9	$148.4	$149.9	$151.4	$152.9
Lunar Surface Innovation Initiative			$119.0	$62.1	$83.7	$78.6	$158.4
Technology Demonstration	**$321.7**		**$397.5**	**$411.8**	**$391.4**	**$362.3**	**$231.2**
Restore/In-Space Robotic Servicing	$130.0	$180.0	$45.3	$45.3	$45.3	-	-
Laser Communications Relay Demonstration *	$21.5		*	*	*	-	-
Solar Electric Propulsion	$34.2		$43.4	$20.9	$4.0	$2.6	-
Small Spacecraft, Flight Opportunities & Other Technology Demonstration	$144.2		$308.8	$345.6	$342.1	$359.6	$231.2
Flight Opportunities	*$15.0*		*$20.0*	*$20.0*	*$20.0*	*$20.0*	*$20.0*
Small Spacecraft Technology	*$17.2*		*$28.3*	*$21.0*	*$20.6*	*$20.7*	*$20.3*
Deep Space Optical Communications	*$26.7*		*$21.3*	*$11.2*	*$4.6*	*$0.9*	
In-Space Robotic Manufacturing & Assembly	*18.3*		*$72.2*	*$65.0*	*$53.0*	*$3.1*	*$0.0*
Precision Landing and LOFTID	*$15.0*		*$44.8*	*$60.7*	*$56.0*	*$48.9*	*$15.2*
Nuclear Surface Power (Kilopower)			*$40.0*	*$70.0*	*$95.0*	*$100.0*	*$85.0*
Cryogenic Fluid Management	*$15.4*		*$55.0*	*$49.8*	*$31.2*	*$49.5*	*$54.6*
SBIR and STTR	**$194.8**		**$210.8**	**$219.1**	**$230.8**	**$237.5**	**$261.0**
TOTAL	**$760.0**	**$926.9**	**$1,014.3**	**$976.1**	**$995.4**	**$964.4**	**$943.1**

*LCRD estimate reflects KDP-C baseline. The project is undergoing a replan due to USAF NGIS spacecraft bus technical and bus problems. Replan is targeted for completion in April 2019.

TECHNOLOGY DRIVES EXPLORATION

SAMPLING OF CURRENT INVESTMENTS



ORION & SLS

3D Woven Compression Pads
Rendezvous and Proximity Operations Sensors
Heat Exchanger
Composite Joints
RAMPT Propulsion Tech

GATEWAY

Solar Electric Propulsion
Optical Communications
In Space Servicing
In Space Manufacturing
Smart Autonomous Systems
Robotic Refueling
GCR Shielding
EM-1 CubeSats

MARS

EDL/LOFTID
MEDLI2
MOXIE
MEDA
NTP
DSOC

LANDER AND SURFACE OPERATIONS

Precision Landing/Sensors

- SPLICE
- Lunar TRN/Doppler Lidar
- Tipping Point Technologies
- High Performance Spaceflight Computing

Cryogenic Fluid Management

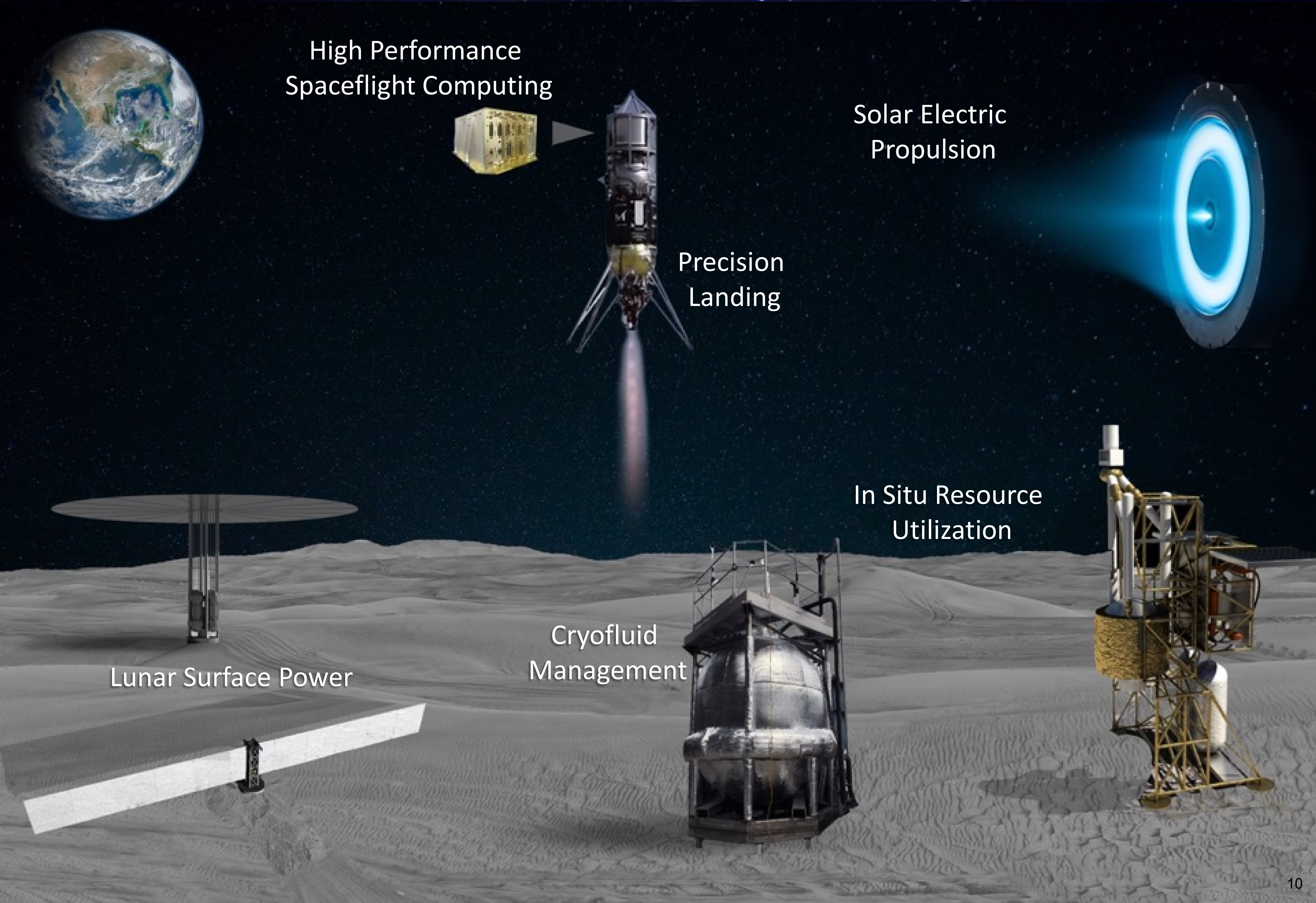
- eCryo
- High Capacity Cryocooler
- Lander Cryo Fluid Demo
- Tipping Point Technologies

In Situ Resource Utilization

Surface Fission Power Demo
Bulk Metallic Glass Gears
Surface Mobility/PUFFER
Deep Space Engine
RAMPT Propulsion Tech

Timelines are tentative and will be developed further in FY2019

Priority Technologies for Flight Demonstration



Lunar Surface Innovation Initiative

In Situ Resource Utilization

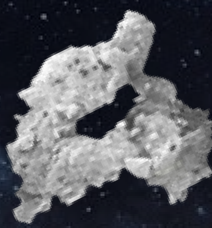
Collection, processing, storing and use of material found or manufactured on other astronomical objects

Surface Excavation/Construction

Enable affordable, autonomous manufacturing or construction

Sustainable Power

Enable continuous power throughout lunar day and night



Lunar Dust Mitigation

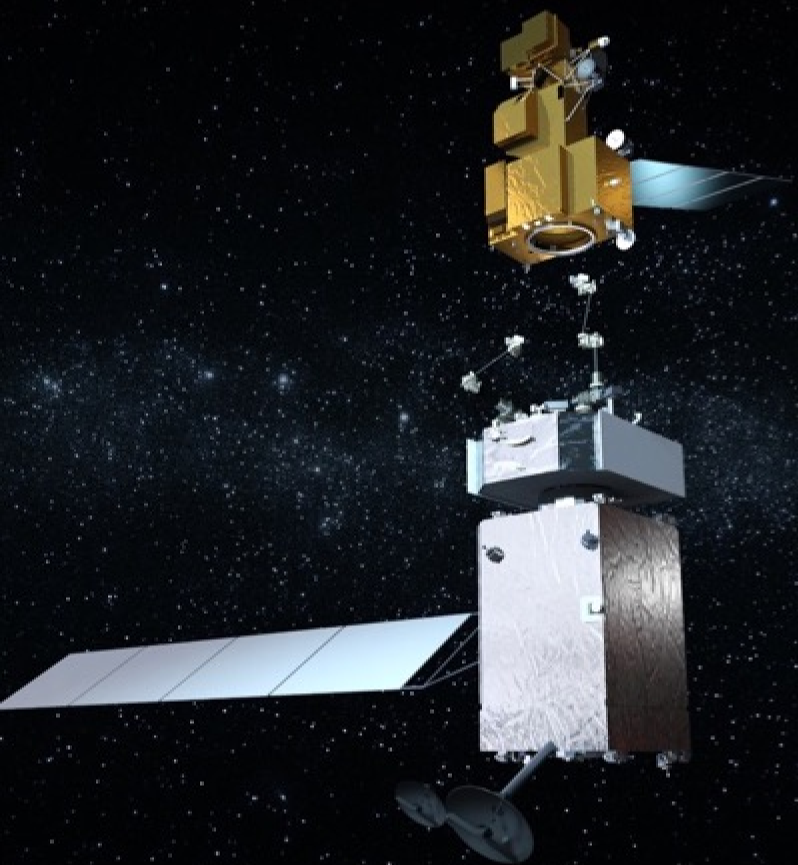
Mitigate lunar dust hazards

Extreme Access

Access, navigate, and explore surface/subsurface areas

Extreme Environments

Enable systems to operate through out the full range of lunar surface conditions



Satellite Servicing, Assembly and Manufacturing Update: Restore-L and IRMA

NAC Technology, Innovation and Engineering Committee Meeting

April 30, 2019

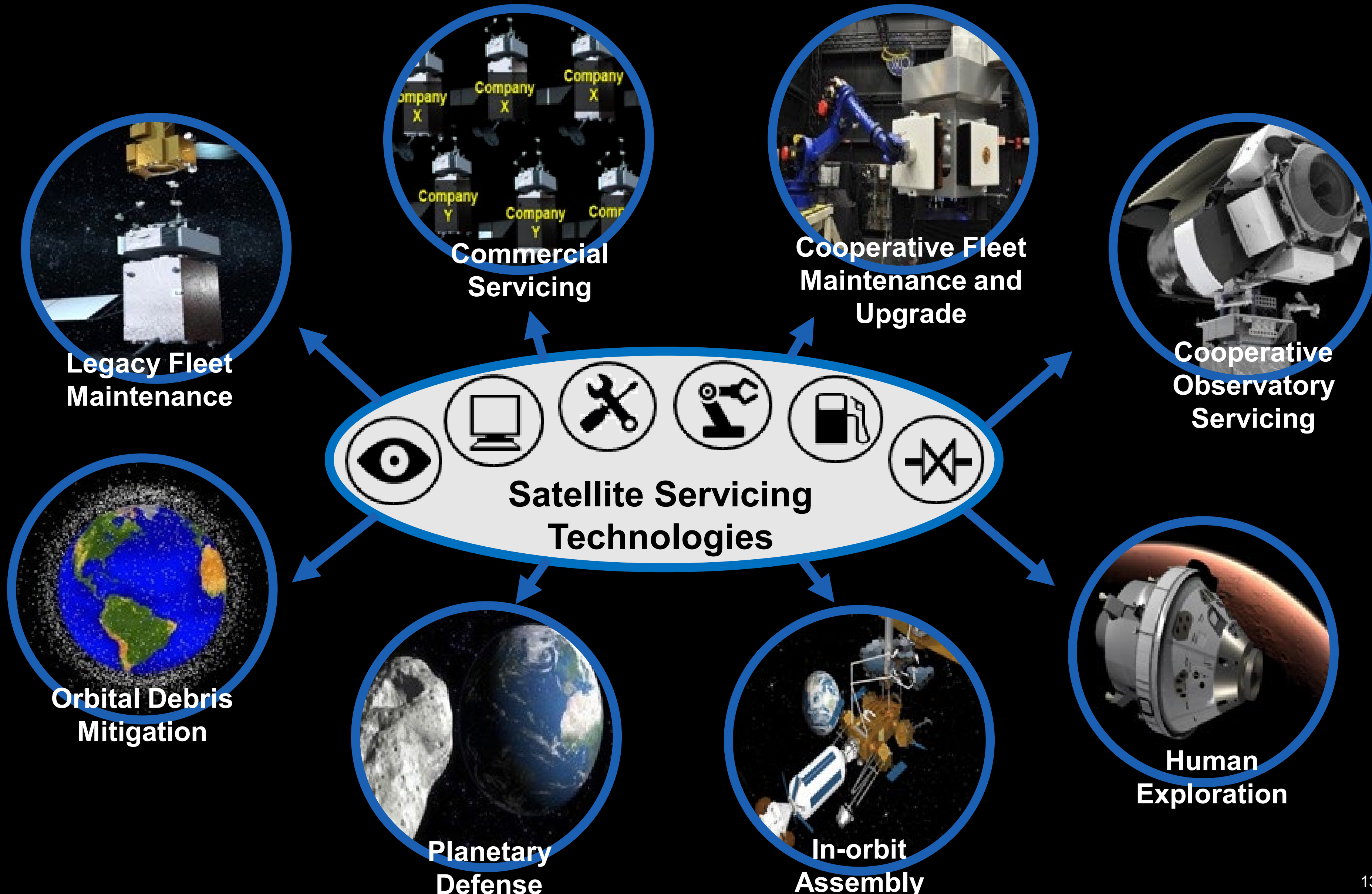
Benjamin Reed

Deputy Director

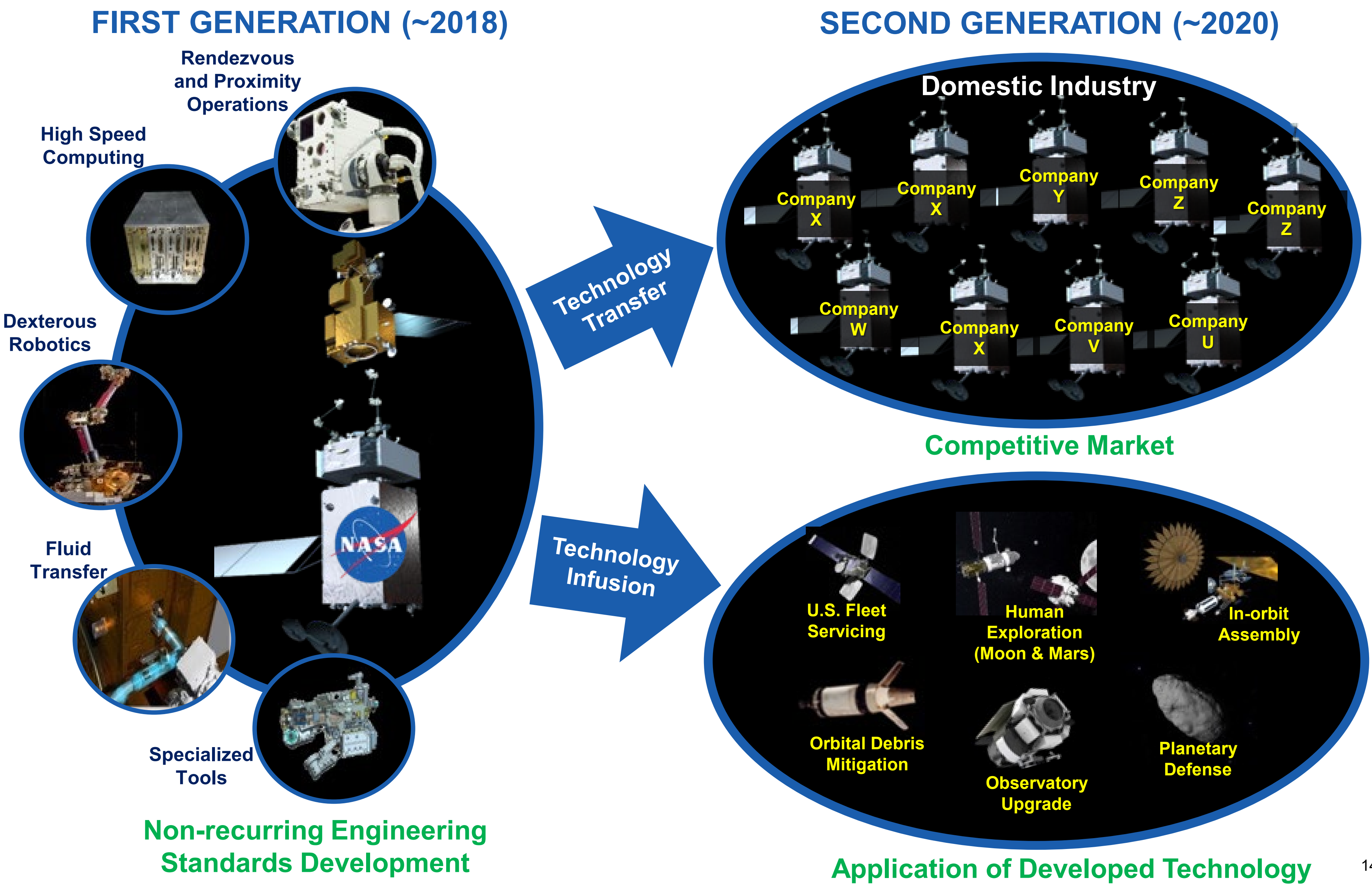
Satellite Servicing Projects Division

NASA’s Goddard Space Flight Center

Future Objectives

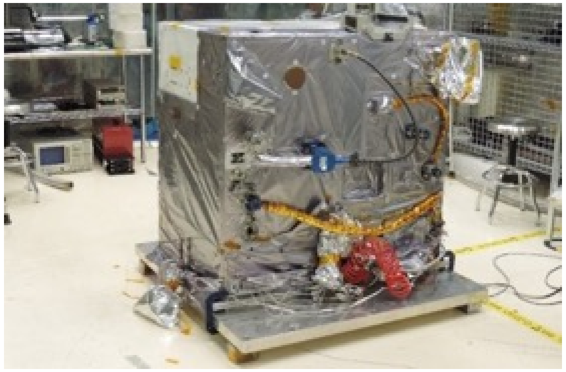


Technology Transfer Enables Robust Servicing Market

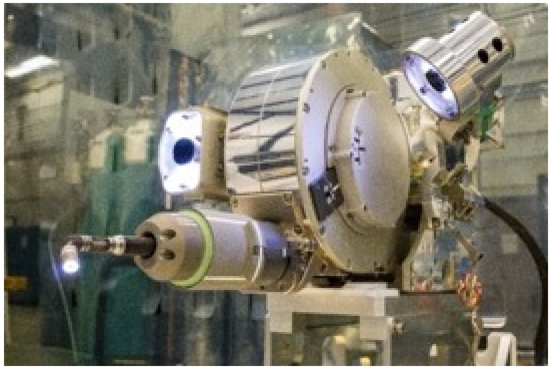


Robotic Refueling Mission 3 (RRM3)

RRM3 objective: mature the tools and techniques for the transfer of cryogenic fluid in orbit. The ability to replenish this critical consumable is important for maintaining spacecraft and for enabling long duration space travel to destinations like the Moon and Mars.

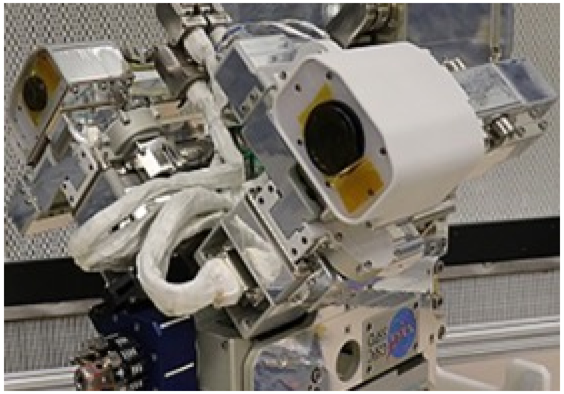


Fluid Transfer Module (FTM)

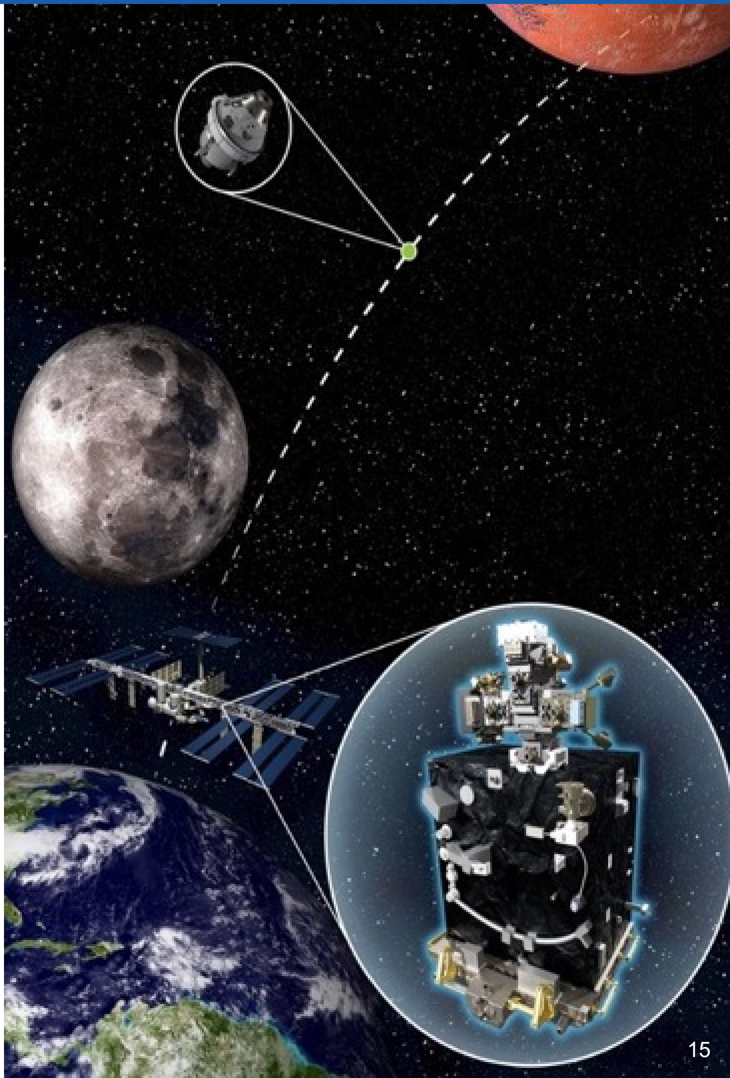


Visual Inspection Poseable Invertebrate Robot 2 (VIPIR2)

Cryogen Servicing Tool CST)



Multi-Function Tool 2 (MFT2)

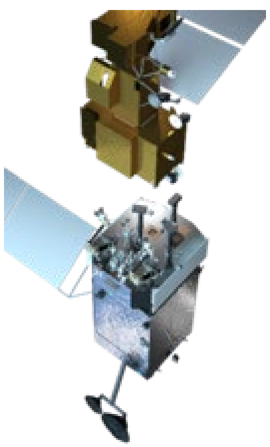


RRM3 Status

- Launched Dec 5, 2018 and installed on ELC 1
- Nominal operations
  - Cryocooler ops for 4 months – zero boil off
  - RF mass gauge (new technology)
  - Pan/Tilt unit nominal operation
  - Motorized zoom lens nominal operation
- Anomaly occurred on April 8, lost ability to power the liquid methane cryocooler
- Temperature of the liquid methane began to rise as expected
- Anomaly team quickly convened and several attempts were made to restore power to cryocooler
- ISS notified the adjacent experiments of the situation
- On April 11 the pressure of the liquid/gaseous methane exceed the safety burst disk pressure and the methane vented to space, as designed. Root cause is under investigation.
- At no point were the ISS crew members at risk
- The tool pedestal with three tools was successfully installed on April 12
  - Cryogen Servicing Tool
  - Visual Invertebrate Poseable Inspection Robot 2 (VIPIR2)
  - Multi-Function Tool 2
- Operations of the three tools are planned for summer 2019
- https://www.nasa.gov/feature/goddard/2019/robotic-refueling-mission-3-update-april-12-2019

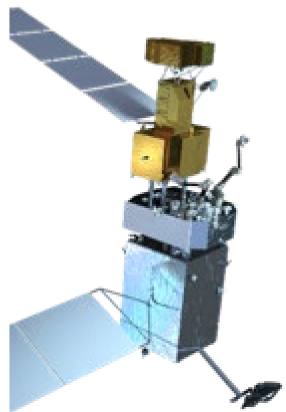
Restore-L

1. Demonstrate national satellite servicing capabilities
2. Advance essential technologies for NASA and national goals
3. Kick-start a new U.S. commercial servicing industry, establishing best practices

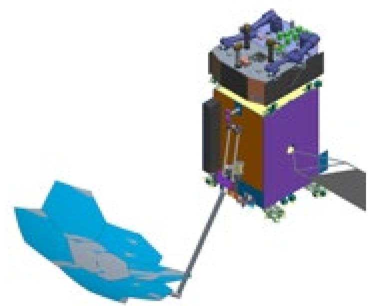


Autonomous Rendezvous, Inspection

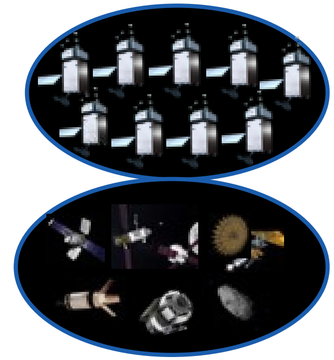
Autonomous Capture



Telerobotic Refuel & Relocate



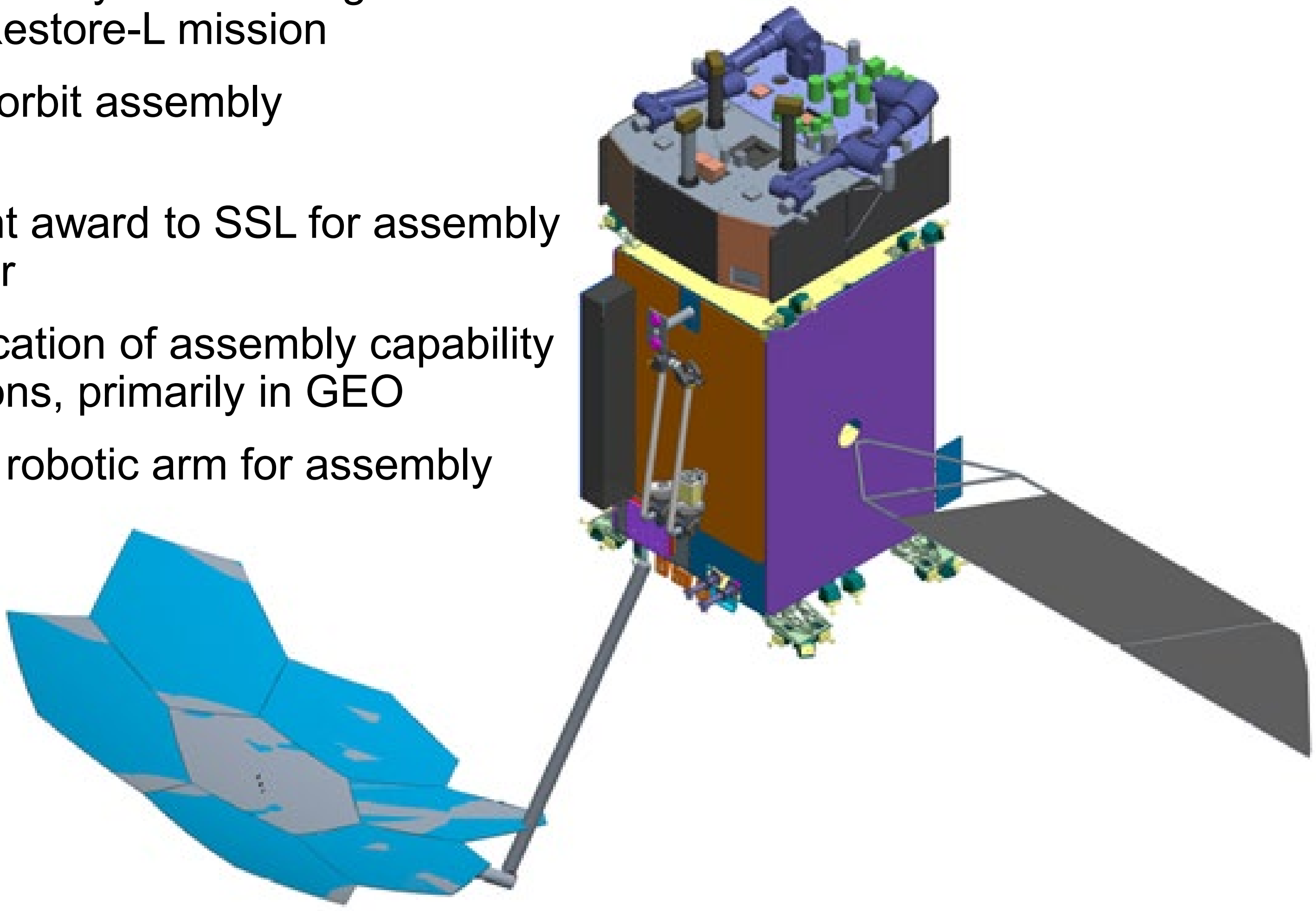
Telerobotic Assembly & Manufacture



Tech Transfer Industry & U.S. Gov

Potential for Dragonfly on Restore-L

- Restore Project is presently establishing a cost and schedule baseline for accommodating Dragonfly – 30 day study concluded good compatibility with Restore-L mission
- Dragonfly is an on-orbit assembly demonstration
- STMD Tipping Point award to SSL for assembly of large RF reflector
- The intended application of assembly capability is for communications, primarily in GEO
- Includes dedicated robotic arm for assembly

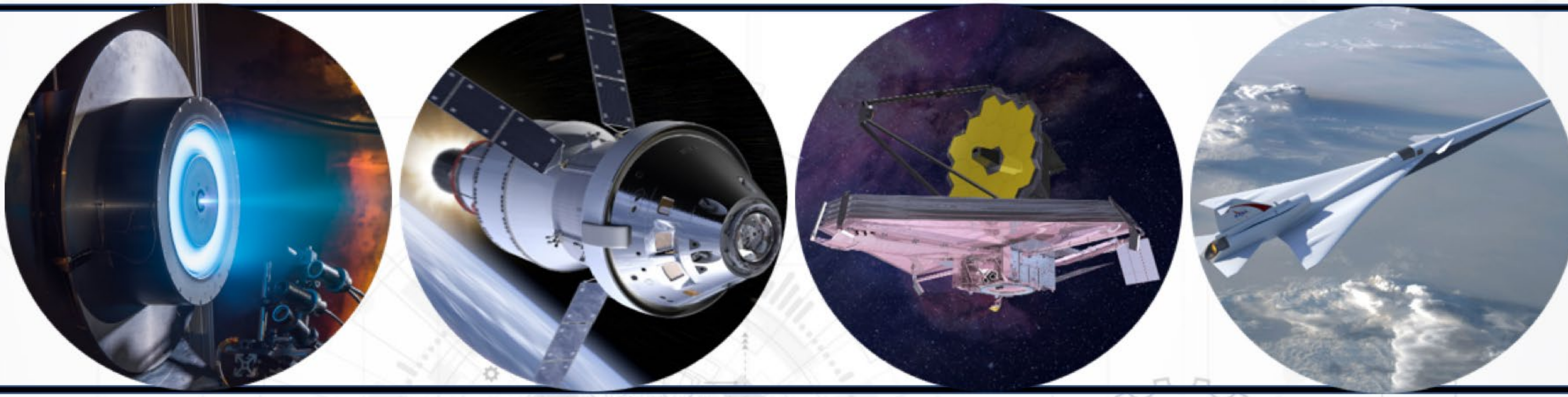


TI&E Finding for STMD AA on Satellite Servicing

- The Committee was impressed by continued progress of satellite servicing with respect to commercialization. For example, the industry events seem to be generating excellent awareness and dialogue.
- The Committee would like to encourage continued focus on the technology infusion to commercial industry as a focus for NASA.

Office of the Chief Technologist

National Aeronautics and
Space Administration



An Update to the
NASA Advisory Council

Technology Innovation and Engineering Subcommittee

30 April 2019

Digital Transformation Initiative

National Aeronautics and
Space Administration

Update to the NASA Advisory Council
Subcommittee on Technology, Innovation and Engineering

DT Drivers, Vision, Goals

Drivers

Digital Convergence	Mission Leadership	Big Data Challenges
Collaboration Needs	Mission Complexity	Research Complexity
Resource Constraints	Workforce Competition	Cybersecurity

Vision

NASA employs powerful digital practices and strengthens its culture of innovation on a transformation journey to enhance efficiency, agility, and insight in the advancement of NASA's mission.

Goals

- Advance DT through opportunity-driven transformative strategic initiatives
- Establish and infuse an Agency-wide, high-impact DT Initiative
- Coordinate and align with mission-enabling, secure, agile enterprise IT services

TI&E Digital Transformation Finding for Chief Technologist

- The Committee was impressed by the Office of the Chief Technologist's efforts thus far in formulating and implementing a plan for a Digital Transformation Initiative: a strategy for NASA to employ digital technologies to transform its processes, products, and capabilities yielding substantial performance improvements.
- The Committee believes OCT's current work is notable, but could also benefit from incorporating input from academic institutions and laboratories, which could be leveraged to enhance the agency's progress and ultimately, its implementation plan.

National Aeronautics and
Space Administration

Space Technology Mission Directorate

Nuclear Thermal Propulsion Update

Sonny Mitchell, NTP Project Manager
Les Johnson, NTP Formulation Manager
Marshall Space Flight Center
30 April 2019

Today's NTP Development

- Past to Present: Changes since Rover/NERVA
  - Increased regulation and cost associated with nuclear operations and safeguards
    - Extensive development of non-nuclear engine components and extensive experience with various types of nuclear reactors
- Emphasis on Low Enriched Uranium (LEU) Fuel
  - Political and international acceptance
  - Programmatic flexibility (optimum mix of NASA, Department of Energy (DOE), industry, and universities)
  - Eliminate significant cost, schedule, and security impacts from attempting to develop and utilize a system containing highly enriched uranium (HEU)
  - Options for real-time exhaust processing or exhaust capture as a method of nuclear rocket engine testing

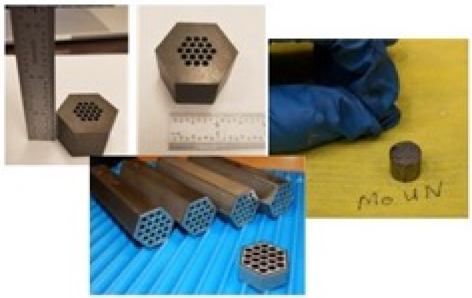
- 55430 lbs thrust
- 1140 MW power using NRX-A5 type fuel
- 28 restarts in 1969
- 11 minutes at full power
- Optimum startup/shutdown sequence

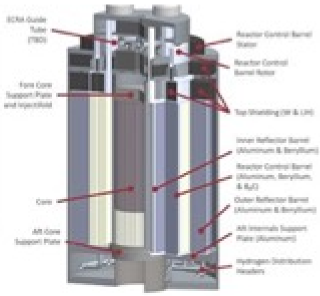
XE' at MSFC

Nuclear Thermal Propulsion (NTP) Project Overview

Project Objective:

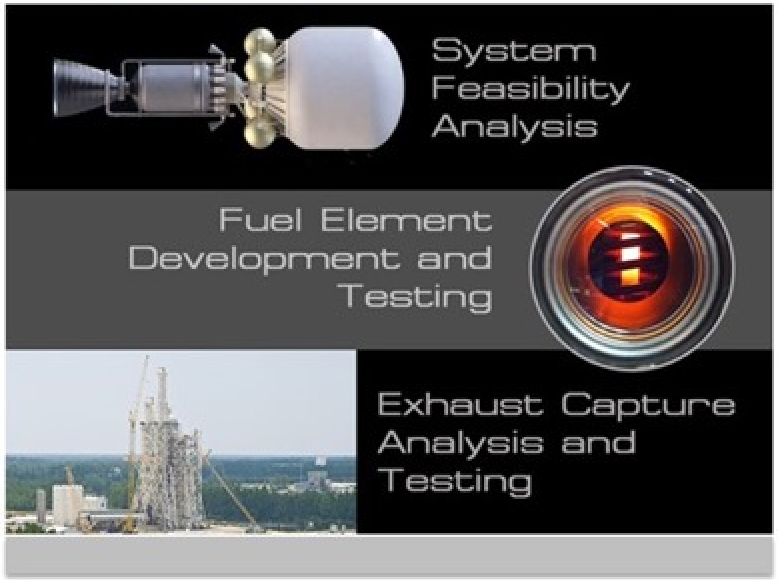
Determine the feasibility and affordability of a Low Enriched Uranium (LEU) - based NTP engine with solid cost and schedule confidence





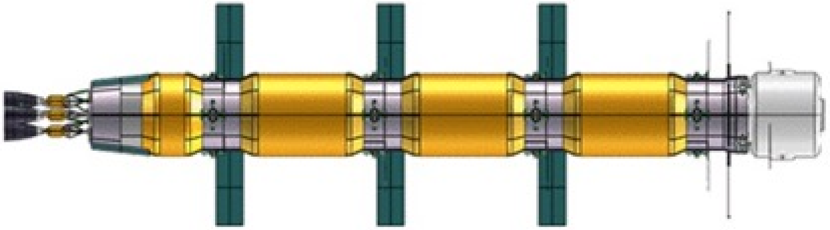
Approach:

- Evaluate the implications of using LEU fuel on NTP engine design
- Fuel element, reactor, and engine conceptual designs and feasibility analyses
- Mature critical technologies associated with LEU fuel element materials & manufacturing
- Develop a method to facilitate ground testing
- Develop relevant cryogenic propellant management technologies



Roles and Responsibilities

- **MSFC**: PM, SE & Analysis Lead, Cryo ConOps Lead, FE Testing
- **GRC**: Cryocooler Testing, Cryo ConOps Support, Sys. Analysis Support
- **SSC**: Engine Ground Testing Analysis
- **KSC**: Ground Processing ConOps / Propellant Densification
- **Aerojet Rocketdyne**: LEU Engine Analysis
- **AMA:** Engine Cost Lead; Cryogenic Fluid Management Support
- **Aerospace:** Engine Cost Independent Review
- **BWXT:** Fuel Element (FE) / Reactor Design/Fabrication
- **DOE:** FE / Reactor Design and Fabrication Support



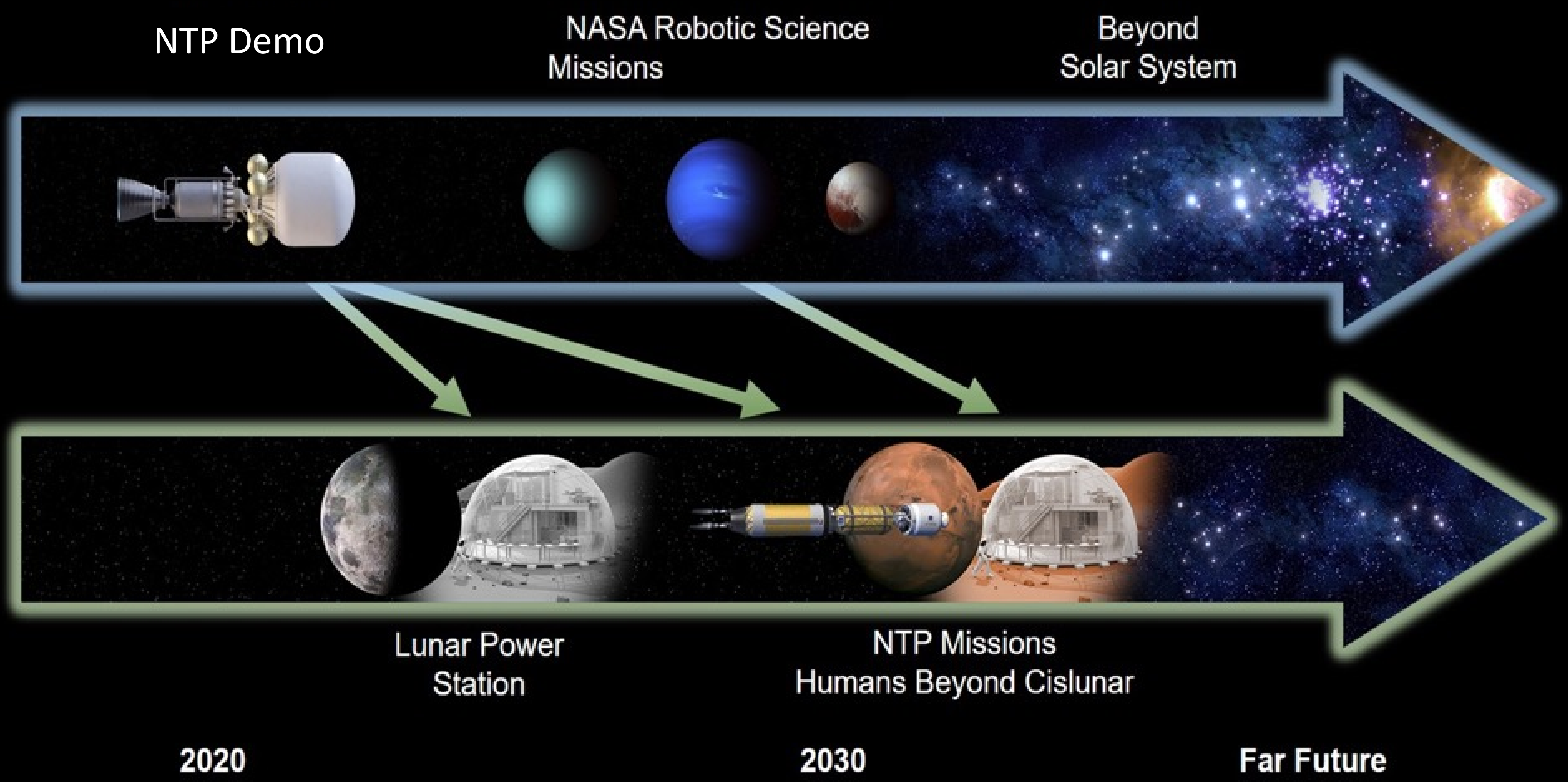
NTP Technology Development Challenges

- **Nuclear Fuels / Reactor**
  - High temperature/high power density fuel
  - Unique moderator element/control drums/pressure vessel
  - Short operating life/limited required restarts
  - Space environment
- **Integrated engine design**
  - Thermohydraulics/flow distribution
  - Structural support
  - Turbopump/nozzle and other ex-reactor components
  - Acceptable ground test strategy (technical/regulatory compliant)
- **Integrated stage design**
  - Hydrogen Cryogenic Fluid Management
  - Automated Rendezvous and Docking

NTP can provide tremendous benefits. NTP challenges comparable to other challenges associated with exploration beyond earth orbit

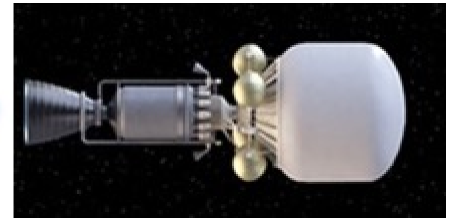
NTP Flight Demo

NTP Demo: First Step



NTP Flight Demo Options

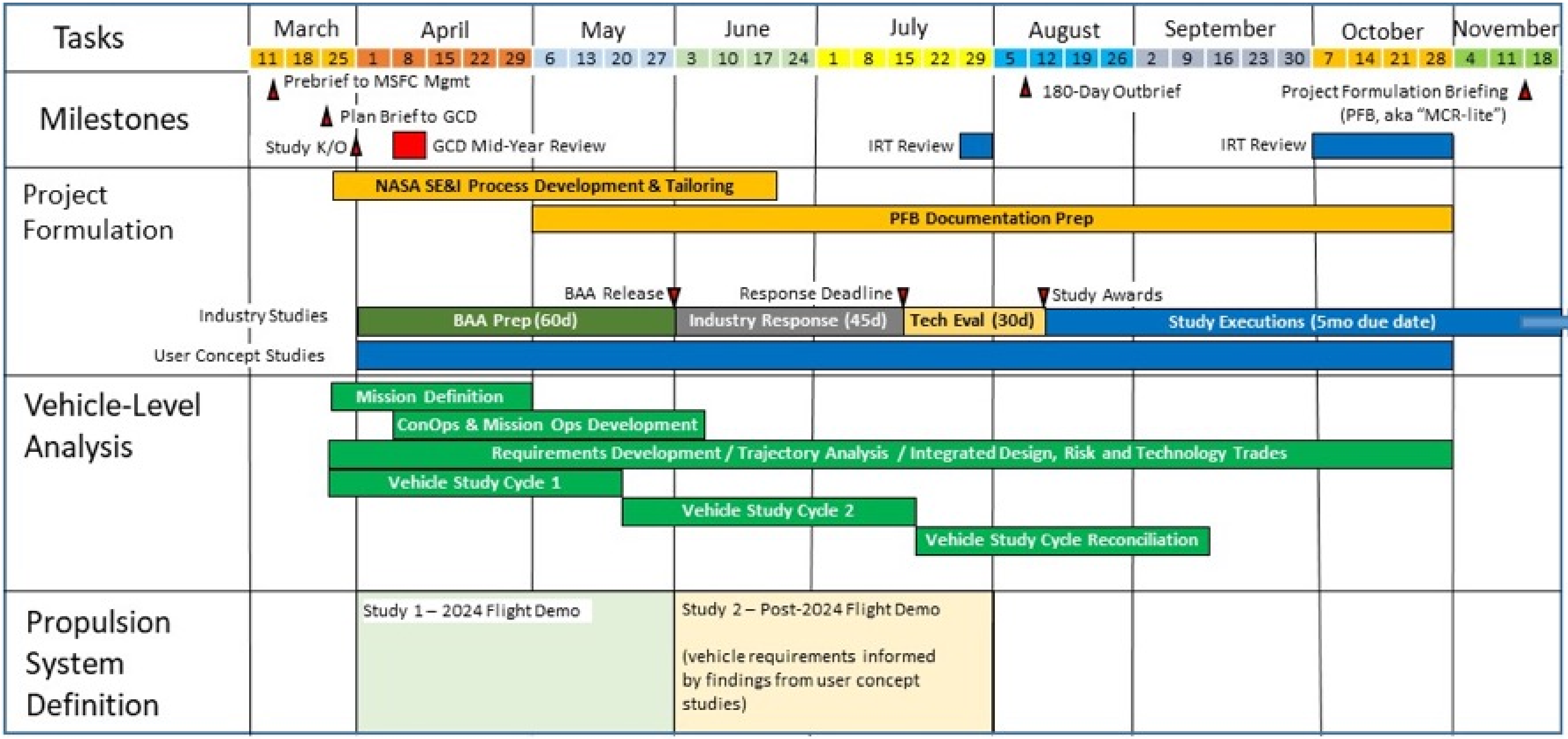
NTP Flight Demo Development



ASAP

- **Flight Demo (FD) Options to be Considered**
  - FD1 - Nearest Term, Traceable, TRL Now (Target FY24 Flight Hardware Delivery)
  - FD2 - Near Term, Enabling Capability (TBD availability Date)
- **Customer Utilization Studies**
  - Science Mission Directorate
  - DoD (via DARPA)
- **Industry Perspective (Industry Day; BAA to be issued)**
- **Outbrief to STMD will provide “MCR-like” products**
  - Including acquisition strategy, draft project plan, certification strategy, etc.

NTP FD Formulation Study Schedule



- CE and LSE will insure alignment across all ongoing study activities
- Leverage previous design work as starting point for current design work
- The first vehicle study cycle will focus on the FD1 mission concept, which will be expanded in subsequent cycles to work the FD2 mission concept studies which will be informed by findings from the user concept studies.
- BAA study responses are expected in early 2020; will work to enable earlier industry inputs via utilizing "Industry Day" approach

TI&E Nuclear Thermal Propulsion (NTP) Finding

- The Committee believes an NTP system could reduce crew transit time to Mars and increase mission flexibility which would enable a human exploration campaign
- The Committee finds much progress has been made by STMD's NTP project which is addressing the key technology challenges related to determining the feasibility and affordability of an LEU-based NTP engine. For example:
  - The project is maturing technologies associated with fuel production, fuel element manufacturing and testing
  - The project is developing reactor and engine conceptual designs
  - The project is performing a detailed cost analysis for developing an NTP flight system
- The Committee notes there is considerable stakeholder interest in doing a near-term NTP flight demonstration mission. STMD is responding by initiating a "mission concept-like study" which will bring together industry and OGAs to evaluate concepts to execute a flight demonstration mission in the near-term timeframe.
- Once current STMD NTP assessments and studies are completed, the Committee encourages Agency leadership to provide clear direction on the future course of NTP development.

March 2018: TI&E Committee Finding

NASA's major missions have been enabled by technology investment over a number of years.

Previous experience with housing "seed corn" and crosscutting technologies in development mission directorates produced unfortunate results

- Drastic reductions in those technology budgets
- Alienation of university connections—the major source of human capital for NASA and its contractors

STMD was established to reverse these outcomes and has produced a robust technology portfolio with university and industry partnerships.

Question: With the potential demise of STMD, how would NASA in its new structure assure future such unfortunate results don't materialize?

August 2018: NAC Recommendation

NAC Recommendation (March 2018)

"The Council recommends that the NASA Administrator task the Acting Associate Administrator to develop and present to the Council mechanisms and/or a hybrid organization that promotes and protects appropriate levels of investment in early and mid-stage technology development and University grants and fellowships. This includes defining metrics to assess effectiveness."

NASA Response

"NASA concurs. This recommendation is being addressed within the larger context of an Agency restructuring activity led by the Associate Administrator. As soon as the Administrator makes a final decision on restructuring the Agency and has briefed various stakeholders, the Associate Administrator will brief the NASA Advisory Council on the Agency restructuring including how the new structure will ensure appropriate levels of investments in early and mid-stage technology development and university grants and fellowships. It is anticipated this briefing will occur at the NASA Advisory Council meeting this summer."

NASA Advisory Council Recommendation

Organizational Options to Promote Technology Investment and University Grants and Fellowships 2018-01-01 (TIEC-01)

Recommendation:
The Council recommends that the NASA Administrator task the Acting Associate Administrator to develop and present to the Council mechanisms and/or a hybrid organizational option that promotes appropriate levels of investment in early and mid-stage technology development and University grants and fellowships. This includes defining metrics to assess effectiveness.

Major Reasons for the Recommendation:

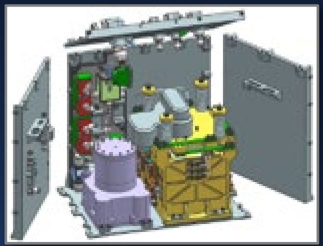
- NASA needs cutting edge technologies to undertake its missions.
  - NASA "grand" missions are technology-enabled.
  - James Webb Space Telescope (JWST), Mars Science Laboratory (MSL), International Space Station (ISS) - type of work NASA should be doing.
  - Demonstrates NASA/U.S. technical leadership.
  - Current missions are based on technologies developed through investments made over several decades.
- In the timeframe FY 2005 – FY 2009, technology budgets (basic research -$500M; applied research -$900M) were drastically reduced.
  - NASA technology shelf depleted over the last decade due to a lack of investment. NASA has begun to correct this over the last three years (e.g., Space Technology Program (STP)).
  - A number of Administrators in the past have organizationally fenced off the budget for "seed corn" and crosscutting investments that includes research and technology and system-level demonstrations to preserve options for the future.
- To reverse this decline, NASA established the Office of Chief Technologist (OCT) in 2010, and the Space Technology Mission Directorate (STMD) in 2013, and rebuilt the crosscutting technology program as well as made focused investments in technology development in the Human Exploration and Operations Mission Directorate (HEOMD) and Science Mission Directorate (SMD).
- STMD university engagement.
  - During the mid-2000s, NASA's university engineering research programs were decimated.
  - STMD reengaged the academic community in engineering research and technology development and has rekindled interest in NASA among students, especially at the graduate level.
  - If appropriate mechanisms are not put in place, NASA interactions with universities will be adversely affected as in the past.

We stand by our concerns and the Council's recommendation

Backup Slides

FY 2019-2020 Plans

MOXIE
March 2019 delivery to Mars 2020 for **July 2020** Launch



Terrain Relative Navigation
December 2018
Delivery for integration on Mars 2020

Laser Comm Relay Demo
Late 2019
Payload delivery for bus integration

Deep Space Optical Comm
Spring 2019 KDP-C for the flight terminal

MEDLI2
April 2019
Hardware Delivery for integration on Mars 2020 entry system

Astrobee
April 2019
Will be headed to ISS for demonstration

In Space Robotic Manufacturing and Assembly project
In 2019 will transition one or more concepts from ground to flight demonstration

High Performance Spaceflight Computing (HPSC)
FY 2020
Completion of critical design

SPLICE
October 2019
Complete NDL environmental testing

Refabricator Delivery and Installation aboard ISS February 2019
The first integrated recycler and 3D printer was successfully installed

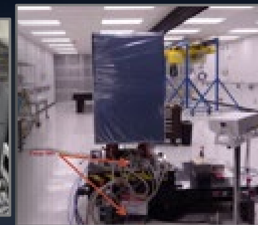
Restore-L
April 2019
Spacecraft critical design review
Late 2019
Mission CDR

Flight Opportunities Campaigns

FY 2019-2020 Plans

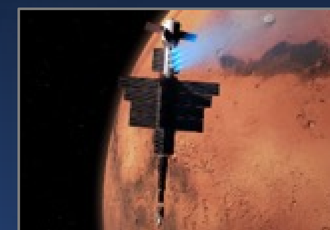
eCryo
December 2019
SHIVER Testing Complete

Deployable Composite Boom
August 2019
Manufactured boom and deployment system will be demonstrated



DSAC & GPIM
NET May 2019
Launch Aboard STP-2

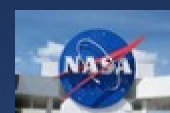
LOFTID
April 2019
Prem. Design Review
July 2020 delivery to launch vehicle



Nuclear Thermal Propulsion
September 2019
System test of a nuclear fuel element that will reduce the risk and demonstrate feasibility of nuclear thermal propulsion

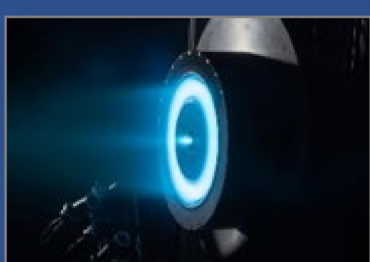
RRM3
November 2018
ISS on-orbit operations of methane cryogenic fluids demo in FY19 and FY20

Extreme Environment Solar Power
July 2019
Developing solar cell concentrator technology for low-intensity, low-temperature space power applications. Hardware will be demonstrated for subsequent technology demonstration on SMD's future mission DART



Space Technology Research Institutes 2018
STRI18 Selection Announcement expected in late March 2019

SpaceCraft Oxygen Recovery (SCOR)
June 2019
Performance test results of two advanced oxygen recovery systems will be available in June 2019 for baseline comparison of capability



Solar Electric Propulsion
FY19: Develop and test EDU/ETU/qualification hardware and complete KDP-C
FY20: Complete Critical Design Review, build qualification units and begin testing.

Composite Technology for Exploration
September 2019
Complete testing of composite joint technology that will reduce launch dry mass

Why NTP?
Architectural Robustness

Architectural Robustness: An insensitivity to required mission energy (the combination of payload mass and DV)

- **Numerous studies have shown that NTP has better system performance than other in-space transportation alternatives**
  - Due to NTP's combination of **high thrust** (~25K lbf/engine) and **high Isp** (~900s)
  - Chemical systems have **high thrust** (~25K lbf/engine) but **low Isp** (~460s)
  - SEP systems have **very high Isp** (~3000s) but **very very low thrust** (~1.5-3 lbf/stage)
- **The robustness offered by NTP can be used to provide flexible mission planning by trading objectives including:**
  - Enables faster trip times for crew
  - More payload
  - Fewer SLS launches
  - Enable off nominal mission opportunities and wider injection windows
  - Enable crew mission abort options not available from other architectures

NTP is a safe, affordable 'game changing' technology for space propulsion that enables faster trip times and safeguards astronaut health.

NTP Fuel Element Fabrication and Test Strategy

	Testing at MSFC	Testing at INL – SIRIUS 1	Testing at INL – SIRIUS 2
Welded Cans ***(with packed powder)***	1 dUN in Mo or Mo/W – Tested in CFEET; dUN in Mo or Mo/W – Tested in NTREES		4 <20% enriched UN in Mo or Mo/W – Tested in TREAT
Traditional Cermet ***(SPS)***	2 dUN in Mo or Mo/W – Tested in CFEET; dUN in Mo or Mo/W – Tested in NTREES		5 <20% enriched UN in Mo or Mo/W – Tested in TREAT
Traditional Cermet ***(SPS)***		3 Uncoated 21% enriched UN in W/Re – Tested in TREAT	

CFEET – Compact Fuel Element Environmental Tester
dUN – Depleted Uranium Nitride
NTREES – Nuclear Thermal Rocket Element Environmental Simulator
SPS – Spark Plasma Sintering
TREAT – Transient Reactor Test Facility
UN – Uranium Nitride

Notes:

1. All Cans and Traditional Cermets have 19 channels
2. UN fill of cans performed at MSFC