National Aeronautics and
Space Administration

Technology, Innovation & Engineering Committee Report
NASA Advisory Council

Mr. J. M. Oschmann | 08.30.18

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: Aug. 28, 2018

- Dr. William Ballhaus, Chair (online)
- Mr. Jim Oschmann, Consultant (in-person Chair)
- Dr. Kathleen C. Howell, Purdue University
- Mr. Michael Johns, Southern Research Institute
- Mr. David Neyland, Consultant
- Dr. Mary Ellen Weber

TI&E Committee Meeting Presentations: Aug. 28, 2018

- Welcome to NASA’s Ames Research Center (ARC)
  - Dr. Eugene Tu, Director, ARC
- Space Technology Mission Directorate (STMD) Update and Discussion
  - Mr. Jim Reuter, Associate Administrator (Acting), STMD
- Autonomous Systems Capability Overview
  - Dr. Terry Fong, Autonomous Systems Capability Leader
- Solar Electric Propulsion (SEP) Update
  - Mr. Todd Tofil, SEP Project Manager, NASA’s Glenn Research Center
- Office of the Chief Technologist Update
  - Dr. Douglas Terrier, Chief Technologist (Acting)
- Annual Ethics Training
  - Mr. Tom Berndt, Chief Counsel, ARC
- In-Space Robotic Manufacturing & Assembly (IRMA) Projects Update
  - Mr. Charles Adams, TDM IRMA Mission Manager
  - Mr. Lawrence Huebner, TDM Project Lead
- Center for the Utilization of Biological Engineering for Space (CUBES) Update
  - Dr. John Hogan, COR, ARC
  - Dr. Adam Arkin, Principal Investigator, University of California-Berkeley

NASA Ames Research Center
An Overview

THANK YOU

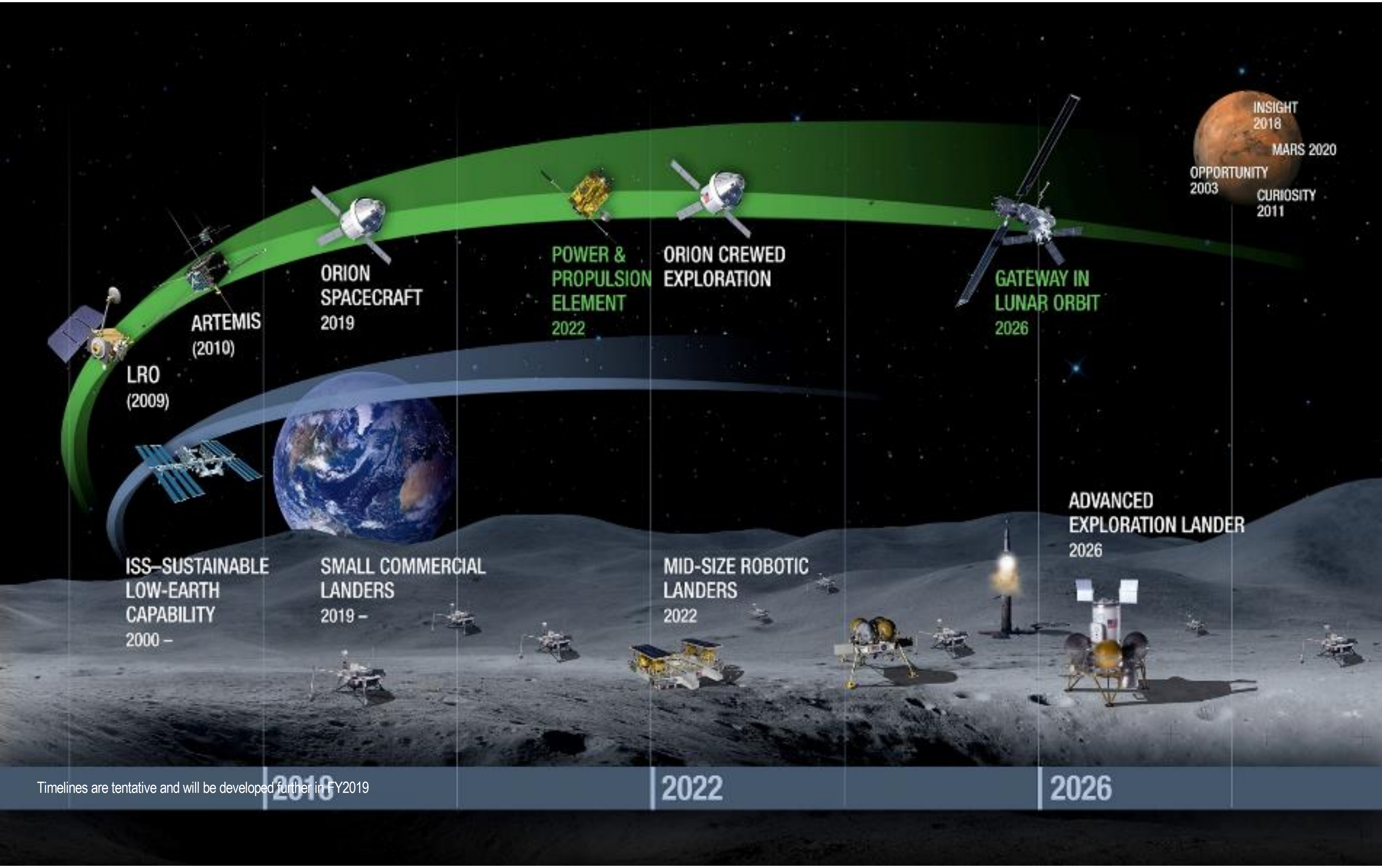
For hosting and tours

Dr. Eugene Tu, Director

Exploration Research and Technology (ER&T)

Mr. James Reuter, Associate Administrator (Acting) for NASA STMD | 08.28.18

EXPLORATION CAMPAIGN



STMD By The Numbers (FY 2018)

>3,000
Proposals Evaluated

>700
Proposals Selected

>300
University Partnerships with >120 Universities

>60
Projects Leading to Flight Demonstrations

>1,000
Active Technology Projects

>1,900
Software Releases

>400
Industry Collaborators

>850
Transitions since 2011

Autonomous Systems
NASA Capability Overview

Terry Fong

Senior Scientist for Autonomous Systems
Space Technology Mission Directorate

2018-08-28

Where can NASA use Autonomy?

EARTH LAUNCH AND LANDING SYSTEMS

- Launch Vehicles
- Launch Abort Systems
- Entry, Descent and Landing

EARTH ATMOSPHERIC SYSTEMS

- Unmanned Aerial Systems
- Vehicle Mission Safety
- Vehicle Performance Enhance
- Human-machine teaming
- National Airspace Management
- Distributed Large-scale Collaborative Systems

GROUND SYSTEMS

- Mission Operations
- Visualization and Interaction
- Robotic Inspection and Repair
- Propellant/Commodity Loading

ROBOTIC EARTH-ORBITING SYSTEMS

- Formation Flying
- Constellations and Swarms
- Rendezvous and Docking
- On-Orbit Servicing
- In-Space Assembly
- In-Space Manufacturing
- Instrument Data Analysis
- Sensor Web

HUMAN EARTH-ORBITING SYSTEMS

- Life Support
- Rendezvous and Docking
- On-Orbit Servicing
- Visualization and Interaction
- Robotic Assistants
- Mission and Data Analysis
- In-space Manufacturing
- In-space Assembly

ROBOTIC SPACE SYSTEMS

- Planetary Ascent Vehicles
- Rendezvous and Docking
- Entry, Descent & Landing
- In Situ Access
- Sample Collection
- Orbital Navigation
- Instrument Data Analysis
- In Situ Resource Utilization

HUMAN SPACE SYSTEMS

- Planetary Ascent Vehicles
- Life Support
- Rendezvous and Docking
- Entry, Descent & Landing
- Surface Transport
- Robotic Assistants
- Mission and Data Analysis
- In Situ Resource Utilization

Astrobee (STMD)

Free-flying robot for ISS IVA

- 3 robots + docking station
- Open-source software
- Autonomous / telerobotic operations

IVA tasks in human spacecraft

- Mobile surveys (inventory + IVA environment monitoring)
- Mobile camera for mission control

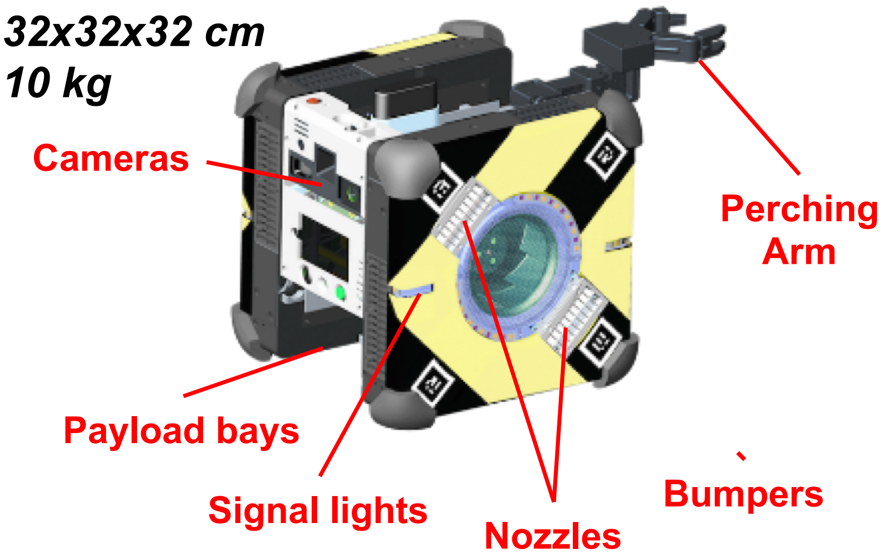
Successor to SPHERES

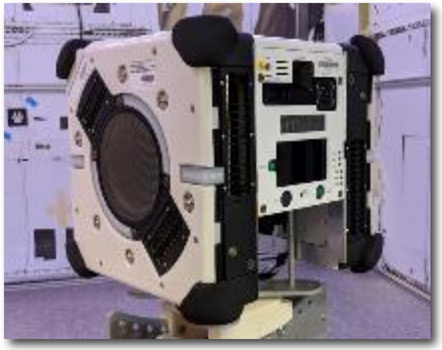
- Multiple ports for new payloads
- Perform experiments without crew
- 7 guest science projects in devel.

Tech development for Gateway

- Support IVA robotics engineering
- Autonomous caretaking during uncrewed periods
- In-flight maintenance

32x32x32 cm
10 kg





Certification Unit (8/2018)

Two Astrobees moving cargo (artist concept)

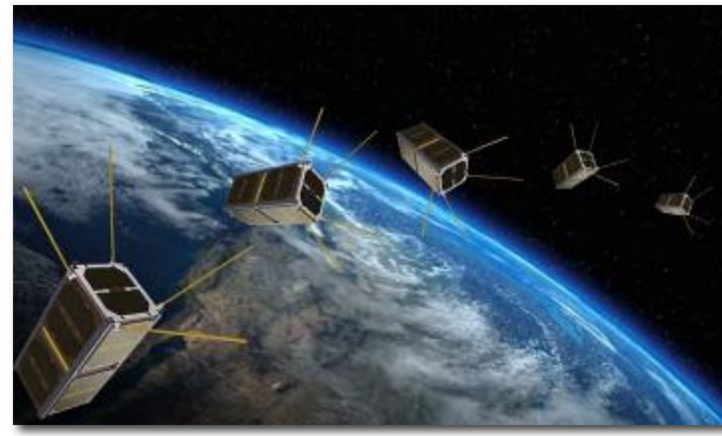
Launch: NG-11 in April 2019

Distributed Spacecraft Autonomy (STMD)

NEW

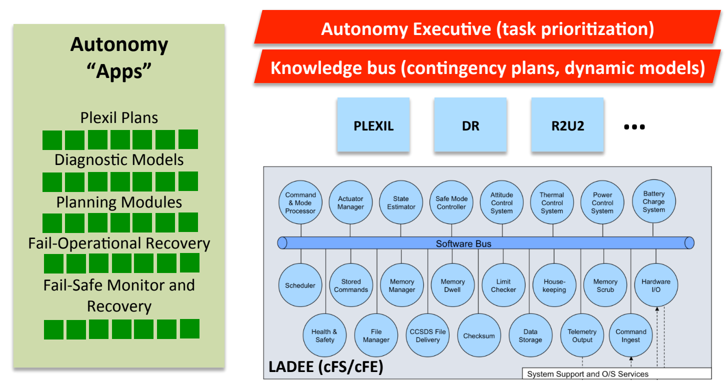
Scaleable autonomy for multi-spacecraft

- Comm: resilient data distribution
- Fault management: distributed diagnostics engine
- Distributed planning, scheduling, and task execution
- Ops: scaleable ground data system and human-system interaction



Flight demonstration

- Integrated to Starling / Shiver mission
- Reusable core software stack
- Dynamic inter-spacecraft coordination for monitoring variable RF signals



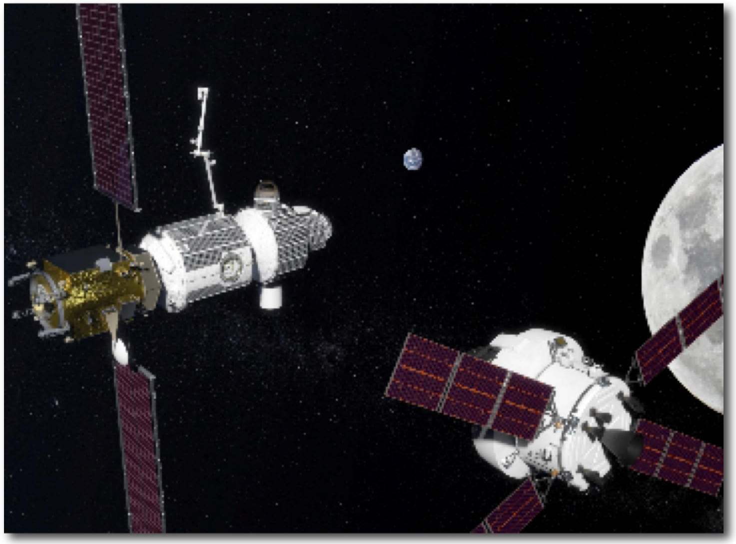
Note: project is completing formulation for FY19 start

Integrated System for Autonomous and Adaptive Caretaking (STMD)

NEW

Caretaking of exploration spacecraft

- Autonomous robots + spacecraft infrastructure (avionics, sensors, networking) + ground control
- Develop and test on ISS for future infusion to Gateway

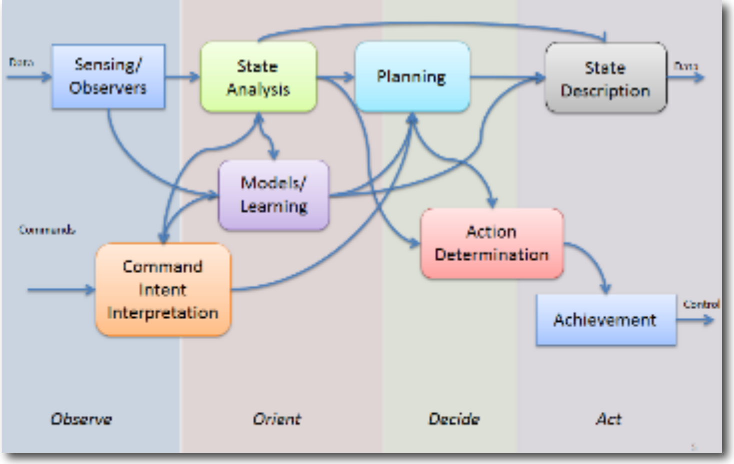


Crewed periods

- Off-load routine work from astronauts
- Tech: safe human-robot interaction, robust navigation

Uncrewed ("dormant") periods

- Monitor and maintain systems in the absence of astronauts
- Tech: sw architecture, diagnostics/prognostics, smart downlink



Solar Electric Propulsion Project

Presentation to the NAC Technology, Innovation and Engineering Committee

August 28, 2018

Todd Tofil
Project Manager

Solar Electric Propulsion (SEP) Project

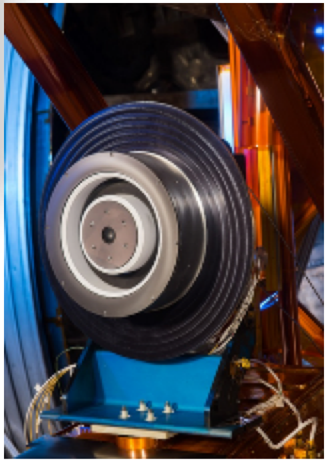
- **The SEP project is managed at the Glenn Research Center (GRC) and funded by the Space Technology Mission Directorate (STMD)**
- **The SEP objectives:**
  - Develop higher-power SEP technologies that benefit US government and private-sector missions
  - Perform on-orbit demonstrations that advance the maturity of high-power solar electric propulsion technology
- **Solar electric propulsion uses electricity to ionize atoms of a propellant. The ions are expelled by an electric field, producing thrust.**
- **The SEP sub-projects to achieve the objectives include:**
  1. The Advanced Electric Propulsion System (AEPS) contract
  2. GRC and Jet Propulsion Lab (JPL) in-house Hall thruster and Power Processing Unit (PPU) risk reduction
  3. SEP Testbed
     - End-to-end electric propulsion string ground test capability
  4. Plasma Diagnostics Package (PDP)
     - Thruster plume data


Hall Thruster

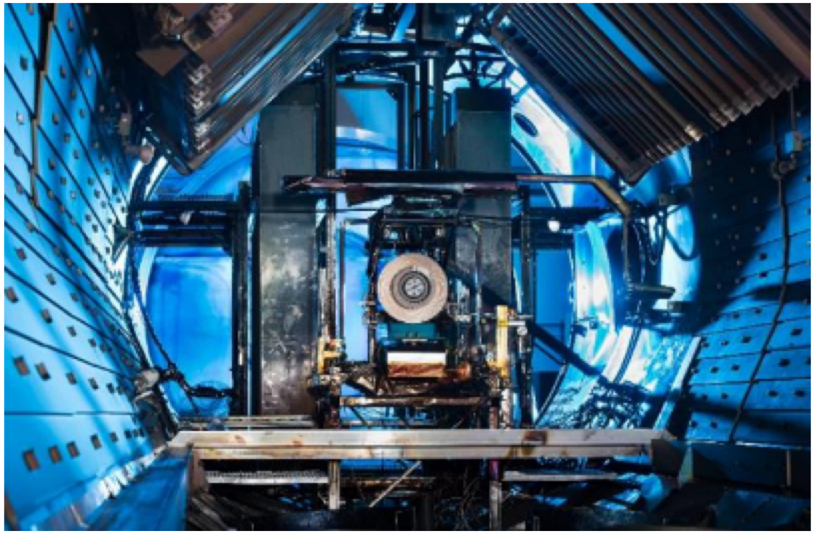
Solar Electric Propulsion Executive Summary

- **Solar electric propulsion will be manifested on the Power and Propulsion Element (PPE) mission**
- **The PPE mission prime contractor will procure EP strings for the mission**
- **Possible demo of 1 Advanced Electric Propulsion system (AEPS) string on high power solar electric propulsion Air Force demo**
  - Working with Space and Missile Systems Center

Power processing unit for an electric propulsion system



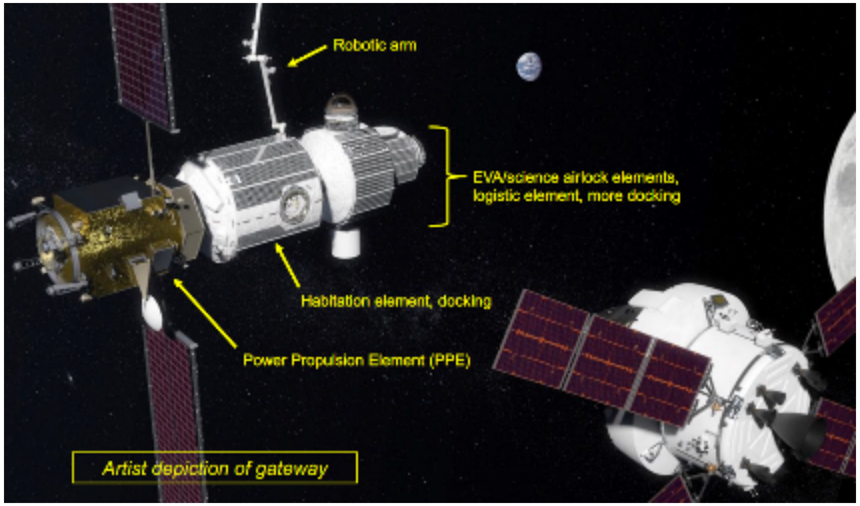
NASA's Technology Demonstration Unit TDU-3



Technology Demonstration Unit (TDU) in 4.6m diameter x 18.3m vacuum facility VF-5

SEP Importance to the Power and Propulsion Element (PPE)

- **NASA is planning to build the Gateway in the 2020s**
- **The platform will consist of at least a power and propulsion element and habitation, logistics and airlock capabilities**
- **The power and propulsion element will be the initial component of the gateway, and is targeted to launch in 2022**
- **The notional set of NASA PPE demonstration objectives include:**
  - Demonstrate high-power 50kW class solar array and electric propulsion technology in relevant space environments
  - Demonstrate integrated solar electric propulsion end-to-end system performance in relevant space environments
  - Demonstrate extended autonomous high power SEP operations in deep space

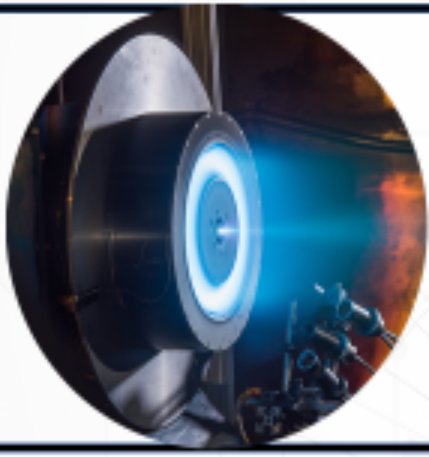
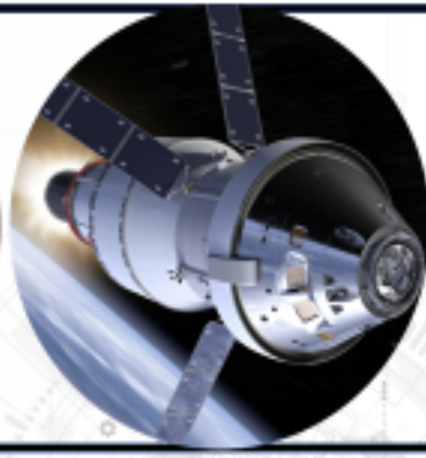
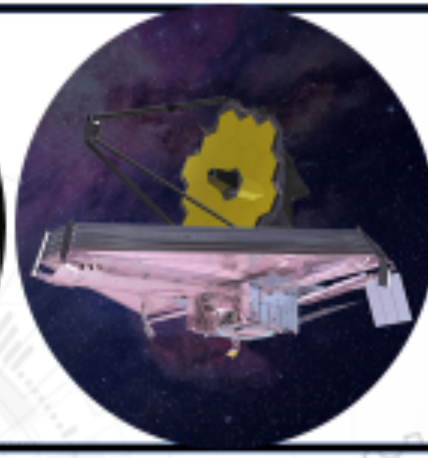


Artist depiction of gateway

https://www.nasa.gov/feature/nasa-s-lunar-outpost-will-extend-human-presence-in-deep-space

Office of the Chief Technologist

National Aeronautics and
Space Administration


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

August 27, 2018

National Aeronautics and Space Administration

Science & Technology Partnership Forum

S&T Partnership Goals
- Leverage synergies
- Influence agency portfolios

S&T Partnership Objectives
- Facilitate synergistic collaborations
- Strategize technical solutions
- Maintain awareness of S&T investments
- Identify impediments and formulate solutions

The USAF, NASA, and NRO are aggressively collaborating to find enterprise synergistic S&T solutions to benefit the Nation.

AFRL
AFOSR
NRL
AF SMC
OUSD
DARPA
NOAA

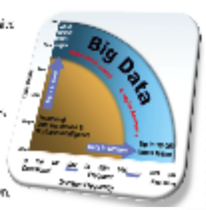
Affiliate government partners dependent on the S&T topic area

Established in 2015

Strategic forum established to identify synergistic efforts and technologies.

Focus on key pervasive and game-changing technologies across government space

Identified and prioritized S&T collaboration topic areas



1. Small Satellite Technology
2. Big Data Analytics
3. In-Space Assembly
4. Cybersecurity

2017-2018 Accomplishments
- Transitioned Topic 1
- Conducted multiple interagency technical exchanges on Topics 3 and 4
- Topic 3
  - Delivered interagency whitepaper describing value proposition, strategic plan, current investments /planning, & concept summaries
  - Defined dictionary of terms, and defined and categorized capability areas
  - Performed capability gap analysis to determine interagency partnering recommendations
  - Topic 3 Industry Open Forum in Nov 2018

Strategic Integration: Current Studies

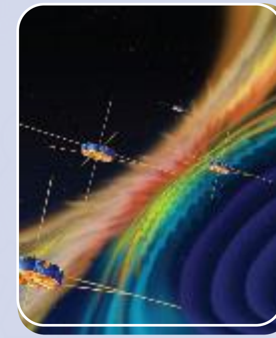
Lessons Learned in Technology Portfolio Management from Outside of NASA

Leveraging OGA and Industry Technology Advances for NASA Missions

Technology Infusion: Over the Valley of Death

Review of Advancement of Critical Technologies for Human Exploration

Behind the $300 Billion Global Space Industry



Emerging and Disruptive Technologies Study

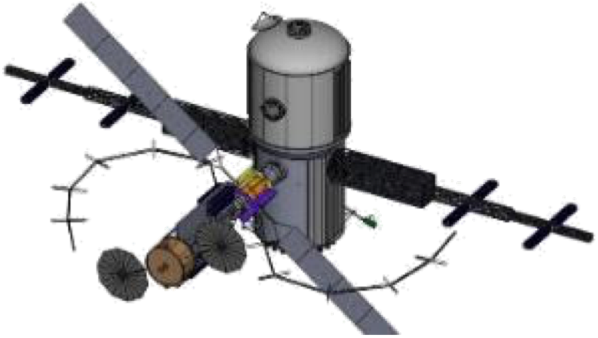
In Space Robotic Manufacturing and Assembly Update
NASA Advisory Council TI&E Committee

Charles Adams, TDM IRMA Mission Manager | 08.28.18

In-Space Robotic Manufacturing and Assembly Update

- The **2015 STMD Tipping Point solicitation** called for technologies needed to assemble, aggregate, and/or manufacture large and/or complex systems in space without astronaut extravehicular activity (EVA).
- With advances in ultra lightweight materials, robotics, and autonomy, **in space manufacturing, assembly, and aggregation concepts are now at a tipping point**.
- This disruptive capability **could transform** the traditional spacecraft manufacturing model by enabling in-space creation of large spacecraft systems, which could **enhance future exploration missions.**

Dragonfly
Space Systems/Loral, LLC



CIRAS
Northrop Grumman

Archinaut
Made In Space

All three contractors performed well during the ground development phase.

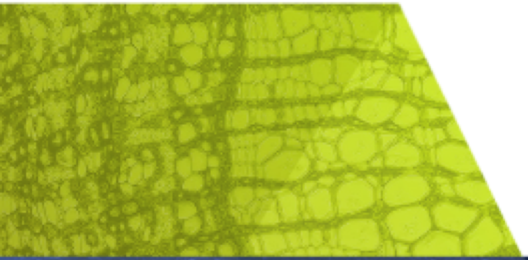
An IRMA Flight Demonstration Phase II procurement is underway with awards budget dependent.

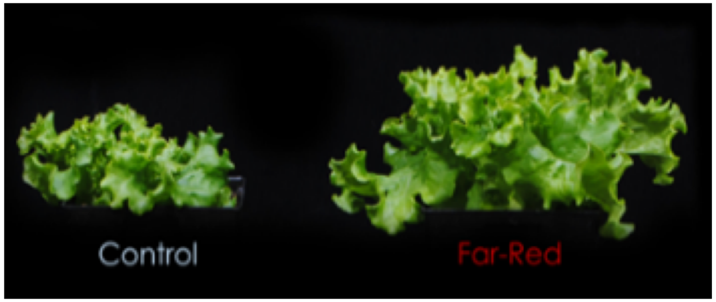
CENTER FOR THE UTILIZATION OF BIOLOGICAL ENGINEERING IN SPACE

MEMBER UNIVERSITIES

Berkeley UNIVERSITY OF CALIFORNIA | Stanford University | UtahState University | UCDAVIS | UF UNIVERSITY of FLORIDA

CUBES DIVISIONS





MICROBIAL MEDIA AND FEEDSTOCKS DIVISION
Harness in situ resources to decontaminate and enrich regolith and to transform human/mission wastes to media and feedstocks for utilization by downstream processes.

BIOFUEL AND BIOMATERIAL MANUFACTURING DIVISION
Produce propellants, biopolymers, and chemicals from media and feedstocks to recycle products at end-of-life and to use generated biopolymers in 3D-printing.

FOOD AND PHARMACEUTICAL SYNTHESIS DIVISION
Plant and microbial engineering to realize food and pharmaceuticals for astronauts along with the recycling of plant wastes.

SYSTEMS DESIGN AND INTEGRATION DIVISION
Optimally allocate and utilize Mars resources to tightly integrate and automate internal processes and to satisfactory achieve performance per mission specifications.

VITAL ROLE OF SPACE TECHNOLOGY IN EXPLORATION

SAMPLING OF CURRENT INVESTMENTS

ORION & SLS

3D Woven Compression Pads
Sensors
Heat Exchanger
Composite Joints
Upper Stage Engine/RAMPT

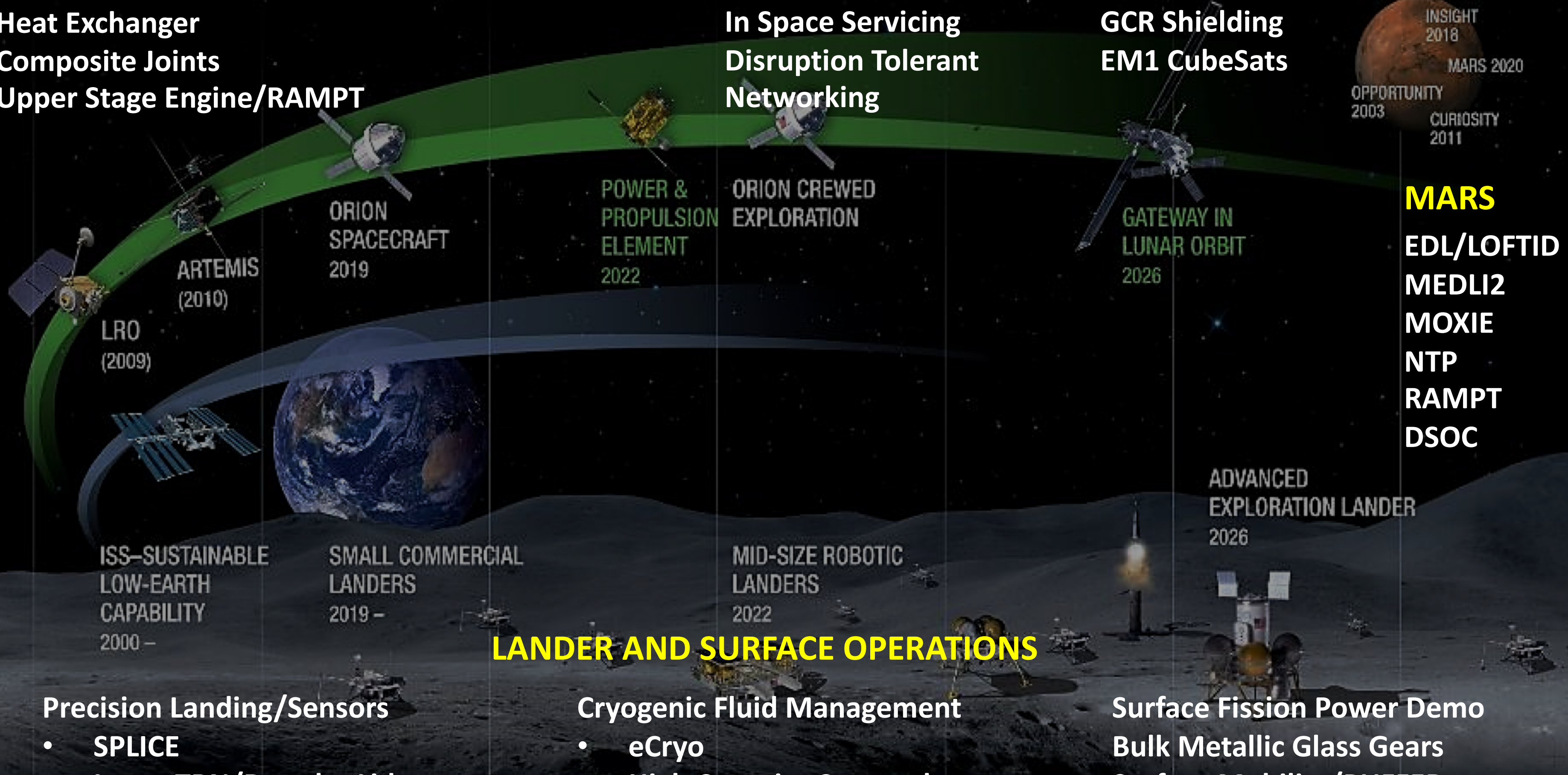
GATEWAY

Solar Electric Propulsion
Optical Communications
In Space Servicing
Disruption Tolerant Networking

Smart Autonomous Systems
Robotic Refueling Mission
GCR Shielding
EM1 CubeSats

MARS

EDL/LOFTID
MEDLI2
MOXIE
NTP
RAMPT
DSOC



LANDER AND SURFACE OPERATIONS

Precision Landing/Sensors
- SPLICE
- Lunar TRN/Dopplar Lidar
- Tipping Point Technologies

High Performance Spaceflight Computing

Cryogenic Fluid Management
- eCryo
- High Capacity Cryocooler
- Tipping Point Technologies

In Situ Resource Utilization

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

Timelines are tentative and will be developed further in FY2019

New STMD New Public-Private Tipping Point Partnerships to Develop Future Space Exploration Technologies

In August, NASA selected 10 proposals from 6 U.S. companies, with a combined award value of approximately $44 million, to develop commercial space capabilities that benefit future NASA exploration missions in new public-private partnerships, including lunar lander and deep space rocket engine technologies.

<table>
<tr><th>Solicitation</th><th>Awardee</th></tr>
<tr><td rowspan="6">Tipping Point</td><td>Blue Origin, L.L.C., in Kent, Washington
• Cryogenic Fluid Management-Enhanced Integrated Propulsion Testing for Robust Lander Services, $10M
• Advancing Sensor Suites to Enable Landing Anywhere on the Lunar Surface, $3M</td></tr>
<tr><td>Space Systems/Loral, L.L.C., (SSL) in Palo Alto, California
• In-Space Xenon Transfer for Satellite, Servicer and Exploration Vehicle Replenishment and Life Extension, $2M
• High Efficiency 6kW Dual Mode Electric Propulsion Engine for Broad Mission Applications, $2M</td></tr>
<tr><td>United Launch Alliance, L.L.C. (ULA) in Centennial, Colorado
Integrated Vehicle Fluids Flight Demonstration, $10M
• Cryogenic Fluid Management Technology Demonstration, $2M
• Mid-Air Retrieval (MAR) Demonstration, $1.9M</td></tr>
<tr><td>Frontier Aerospace Corporation in Simi Valley, California
• Flight Qualification of the DSE, MON-25 MMH Rocket Engine, $1.9M</td></tr>
<tr><td>Paragon Space Development Corp. in Tucson, Arizona
• Cryogenic Encapsulating Launch Shroud and Insulated Upper Stage (CELSIUS) , $1.6M</td></tr>
<tr><td>Astrobotic Technology, Inc., Pittsburgh, Pennsylvania
• Stand-Alone Sensor for High Precision Planetary Landing, $10M</td></tr>
</table>

These Tipping Point Technologies will lead to future exploration capabilities.

TI&E Committee Finding – August 2018

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 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