National Aeronautics and
Space Administration

Technology, Innovation & Engineering Committee Report NASA Advisory Council

Presented by:
Dr. Bill Ballhaus, Chair

November 30, 2016

TI&E Committee Meeting Attendees
November 18, 2016

- Dr. William Ballhaus, Chair
- Mr. Gordon Eichhorst, Aperios Partners, LLP
- Dr. Kathleen Howell, Purdue University
- Mr. Michael Johns, Southern Research Institute
- Dr. Mary Ellen Weber, Stellar Strategies, LLC

TI&E Committee Meeting Presentations November 18, 2016

- Space Technology Mission Directorate Update
  – Mr. Stephen Jurczyk, Associate Administrator, STMD
- In-Space Robotic Manufacturing and Assembly Update
  – Ms. Trudy Kortes, TDM Program Executive, STMD
- Mars Architecture Technology Drivers
  – Mr. William Cirillo, NASA LaRC Systems Analysis and Concepts Directorate
- Chief Technologist Update
  – Mr. Dennis Andrucyk, NASA Chief Technologist (Acting)
- Chief Engineer Update
  – Mr. Ralph Roe, NASA Chief Engineer
- Small Spacecraft Technology Study Update
  – Dr. Bhavya Lai, IDA Science and Technology Policy Institute
- Cyrogenic Fluid Management Investments Overview
  – Dr. Jeff Sheehy, Chief Engineer, STMD

In-Space Robotic Manufacturing and Assembly (IRMA)
Update for NAC TI&E Committee

November 18, 2016

IRMA Portfolio Overview

- IRMA is managed by the Technology Demonstration Mission (TDM) Program for NASA's Space Technology Mission Directorate (STMD).
- Selected from the 2015 STMD Tipping Point BAA with the objective to invest in ground-based development to prepare technology for potential flight demonstration.
- Demonstration is intended to result in:
  - a significant advancement of the technology's maturation.
  - a high likelihood for utilization of the technology in a commercially fielded space application.
  - a significant improvement in the offerors' ability to successfully bring the space technology to market.
- TDM has awarded three contracts which will demonstrate robotic manipulation of structures and remote manufacture of structural trusses. The use of these technologies in relevant environments will ready them for potential flight demonstration and then commercialization.

IRMA Portfolio Overview

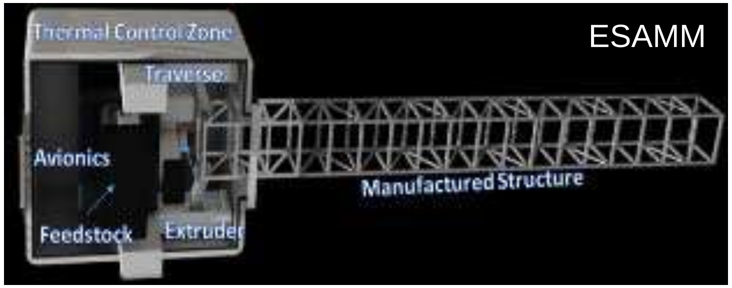
- Key to the Public-Private Partnership concept of these Tipping Point awards is shared investment.
  - Each selected award includes a corporate and/or customer contribution of at least 25% of the total proposed firm-fixed price.
- Each proposal utilizes structures and materials expertise as well as test facilities at two NASA centers
- Each selected proposal included a strong business case for commercializing in-space manufacture, assembly, and maneuvering to enable large structure assembly, satellite servicing, and even re-purposing of satellites.
- The industry partners are focused on the end goal and want to optimize development.
  - “If it doesn't feed the business use case, don’t do it.”

Made In Space, Inc. (MIS)
Archinaut Technology Development

A 2 year ground based risk reduction effort to advance in space manufacturing and assembly technologies for infusion into exploration missions.	7120.8 Ground Demo	Formulation	LCCE: $20 M	TRL: 4 -> 6

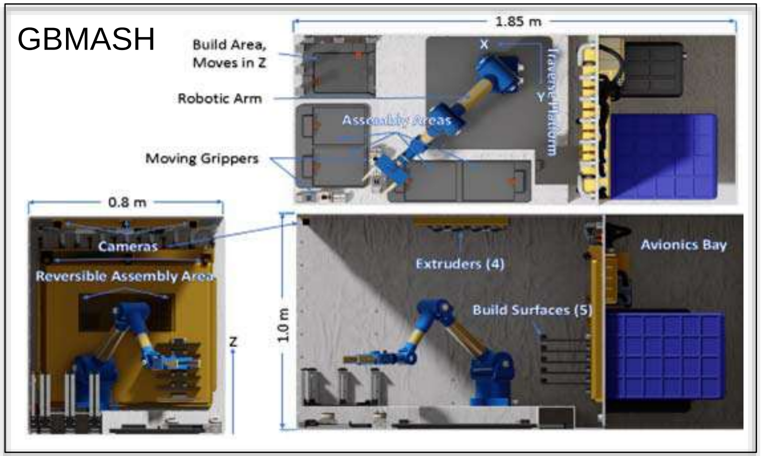
Objectives:

- Demonstrate extended structure additive manufacturing of structures in a relevant environment using Extended Structure Additive Manufacturing Machine (ESAMM)
- Demonstrate additive manufacturing and assembly of structures in a relevant environment using Ground-Based Manufacturing and Assembly System Hardware (GBMASH)
- Evaluate part quality through mechanical and structural testing



Current Status / Accomplishments:

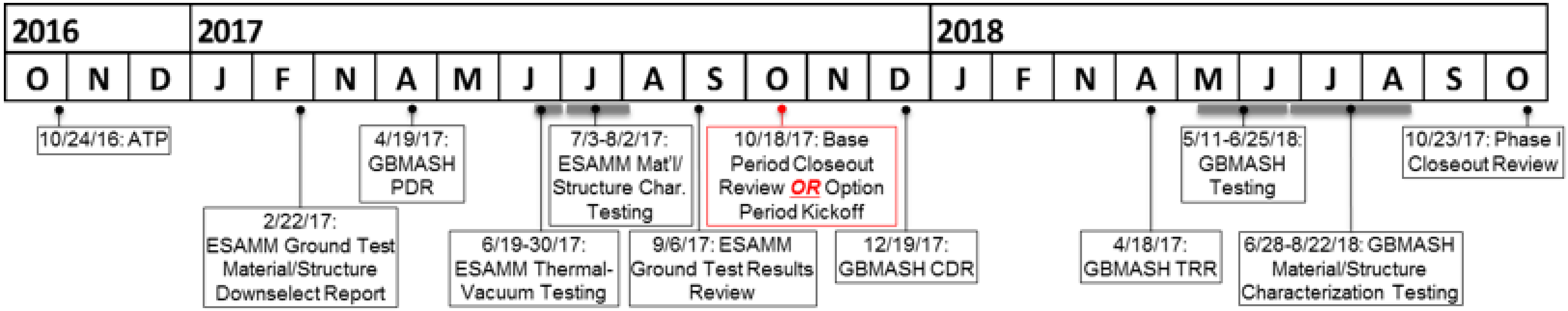
- Contract awarded October 27, 2016.
- Kick-off meeting held November 10, 2016 at ARC.



Team:

- **Made In Space**: Project lead; expertise in in-space additive manufacturing and telerobotics
- **Northrup Grumman Corp. (NGC)**: Lead sub-contract, system integrator
- **Oceaneering Space Systems**: Robotic arm development
- **Ames Research Center (ARC)**: Thermal-vacuum test planning, development, and execution

Schedule:



Orbital ATK
Commercial In-space Robotic Assembly and Services

A 2 year ground based risk reduction effort to advance in space manufacturing and assembly technologies for infusion into exploration missions.	7120.8 Ground Demo	Formulation	LCCE: $20 M	TRL: 4 -> 6

Objectives:

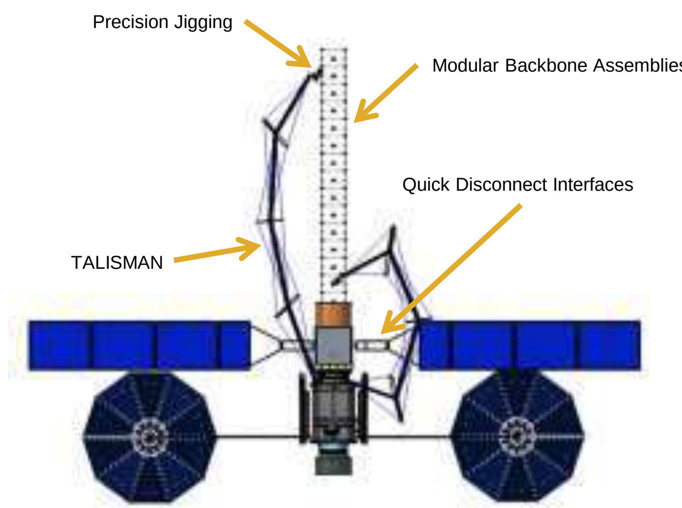
- Demonstrate robotic reversible joining methods for mechanical and electrical connections.
- Develop a feasible concept to validate space assembly geometries.
- Demonstrate repeatable module to module interfaces for in-space structural assembly.

Current Status / Accomplishments:

- Contract awarded on September 22, 2016 .
- Kickoff meeting held at Langley Research Center on October 6, 2016.

Team:

- **Orbital ATK**: Project lead
- **Glenn Research Center (GRC)**: conduct concept feasibility study
- **Langley Research Center (LaRC)**: develop TALISMAN system capable of being used for mission extension vehicle applications.
- **Naval Research Laboratory (NRL)**: Robotic software development



Vision: a robotic assembly, repair, maintenance and refurbishment capability to enable repurposing of spacecraft modules

Schedule:

2016: Aug, Sep, Oct, Nov, Dec | 2017: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec | 2018: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug

- ● 10/6/16: Kick-off Meeting
- ○ 11/15/16: Systems Reqs Review (SRR)
- ○ 3/15/17: EBW Precision Demo
- ○ 5/15/17: Hardware MRR
- ○ 6/15/17: IPJR 2.0 & EBW Simple Jnt Demo
- ○ 7/15/17: Base Period Closeout Rvw
- ○ 8/15/17: Option Kickoff Meeting
- ○ 9/15/17: Begin HW Integration @ LaRC
- ○ 10/15/17: TALISMAN 3.0 Cmpnt Integrat.
- ○ 11/15/17: TALISMAN 2.0 Demo
- ○ 1/15/18: IPJR 3.0 Demo
- ○ 1/15/18: IPJR 3.0 Demo
- ○ 4/15/18: Complete Ground Demo Testing
- ○ 5/15/18: Technology Readiness Review
- ○ 7/15/18: Deliver Final Report

COMPLETED

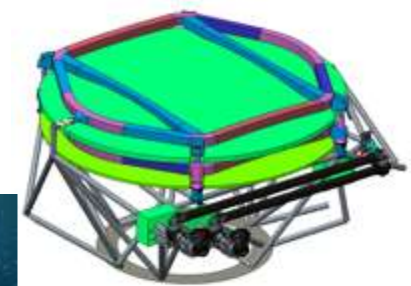
Space Systems / Loral
Dragonfly

A 2 year ground based risk reduction effort to advance in space manufacturing and assembly technologies for infusion into exploration missions.	7120.8 Ground Demo	Formulation	LCCE: $20 M	TRL: 4 -> 6

Objectives:

- Demonstrate effective stowage techniques for larger than traditional solid reflectors into a launch
- Demonstrate assembly interfaces originally designed for EVA operations can be modified for use robotically.
- Demonstrate assembly joints and additively manufactured antenna support structures meet EHF antenna performance requirements.
- Demonstrate a feasible Con-Ops for augmenting an existing GEO Commercial Satellite.

Gripper concept and auto-lock assembly joint



Condensed reflector stowage concept

Vision: an ultra-lightweight robot assembles a large reflector on a comSat in GEO

Current Status / Accomplishments:

- Contract awarded on September 1, 2016.
- Kickoff meeting held in Pasadena, California on September 15, 2016.

Team:

- **Space Systems/Loral (SSL)**: Project lead; design and operations management of mission.
- **Langley Research Center (LaRC)**: develop robotic assembly interfaces
- **Ames Research Center (ARC)**: develop situational awareness software.
- **Tethers Unlimited (TUI):** In-Space Truss Manufacturing
- **MDA US & Brampton:** Robotic Arm and Advanced Robotic Control Software

Schedule:

2016						2017												2018									
J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O

- 9/1/16: ATP
- 12/18/16: Systems Reqs Review
- 5/18/17: TRR for Robotic Reflector Assembly Demo
- 7/18/17: Complete Robotic Reflector Assembly Demo
- 8/18/17: Base Period Close-out Review
- 9/1/17: Option Period Kick-off
- 11/18/17: Option Reqs & Verification Plan Review
- 2/18/18: Option Performance & Interface Reqs Review
- 4/18/18: Complete Environmental Testing
- 5/18/18: Option HW Design Review of Assembly Interface & End Effector
- 8/18/18: Option Period Final Review Robotic Assembly System MCR

COMPLETED

National Aeronautics and Space Administration

Office of the Chief Technologist Update

Presented to the NASA Advisory Council, Technology, Innovation and Engineering Subcommittee

Dennis J. Andrucyk

NASA Acting Chief Technologist

November 18, 2016

Draft 2017 NASA STIP

Office of the Chief Engineer Update

Ralph R. Roe, Jr.

NASA Chief Engineer

November 18, 2016

Technical Capability Assessment Introduction

- NASA Technical Fellows or designee served as Capability Leaders for their ***Discipline***
  - Led agency-wide Technical Capability Leadership Teams; accomplished the enduring, strategic work of the Capability Leadership Model
  - Technical capabilities designated as agency capabilities, not Center or Mission capabilities; functioned as an aligned unit to advance the capability; represent agency stewardship

- NASA Technical Fellows and their Capability Leadership Teams developed a scope, built a baseline from their initial Technical Assessment, and will refine/update the baseline as external or internal changes dictate.

- Process demonstrated the value of agency-level Capability Leadership. Capability leaders are recognized as providing value-added support for related agency activities (e.g., partnership discussions, technology prioritization, etc…).

FY16 Success Stories

- Capability Leadership model has created improved coordination, collaboration and advice within the Engineering community regarding current and future state of the capability
- Stakeholders increased recognition of capability leaders and sought advice on resolving mutual barriers, such as:
  - capability alignment/deployment
  - industry engagement
  - workforce challenges
  - facility challenges
  - technology gaps and priorities
  - IT barriers
- Strengthening integration between capability leadership and capability portfolio management

SCIENCE AND TECHNOLOGY POLICY INSTITUTE

Focus for STMD's Small Satellite Technology Investments – Interim Update

Bhavya Lal, Asha Balakrishnan, Ben Corbin
Alyssa Picard, Jonathan Behrens, Ellen Green
IDA Science and Technology Policy Institute

NAC Technology, Innovation and Engineering Committee Meeting
November 18, 2016

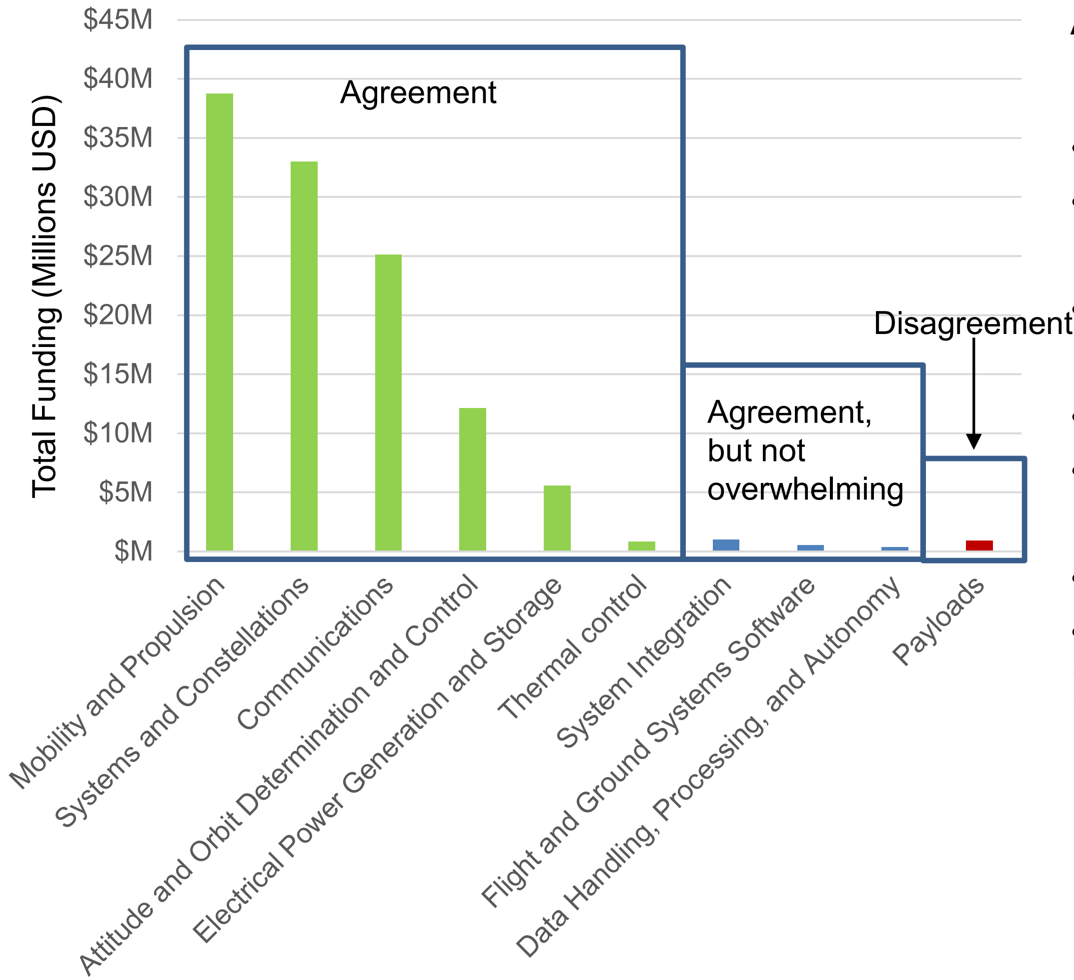
Preliminary Findings/Do Not Cite or Quote

Project Goal

Given investments outside STMD, and NASA's mission needs, what should be the focus for STMD's smallsat investments?

In March 2016, the NASA Advisory Council recommended that "STMD conduct an independent study of current small satellite technology developments to "determine the appropriate focus for NASA's small spacecraft technology investments…NASA is at risk for having STMD's small satellite technology investments duplicated in commoditized capabilities. (consequence of no action)." The committee asked NASA to consider the "the appropriate, discriminating role for STMD vis-à-vis all the other organizations that are developing small satellite technology."

Preliminary Finding: STMD Investments are Generally in the Right Areas



Areas SSTP Currently Not Funding (but stated as valuable)

- Reliability testing
- Development of "plug and play" universal platform
- Miniaturized calibration sources for science payloads
- Deployable systems for science needs
- Development of radiation hardened systems
- Ground station systems/software
- Clearinghouse for testing and parts data
- ➢ *Dedicated smallsat launch*

Note: Chart includes current and future allocations

Next Steps

- Complete interviews (Nov 2016)
- Consider brief survey of performers (Dec 2016)
- Discuss preliminary findings (Nov-Dec 2016)
- Finalize findings and recommendations (Dec 2016)
- Finalize draft report and have external experts provide feedback (Dec-Jan 2017)
- Deliver report to NASA (Feb 2017)

National Aeronautics and
Space Administration

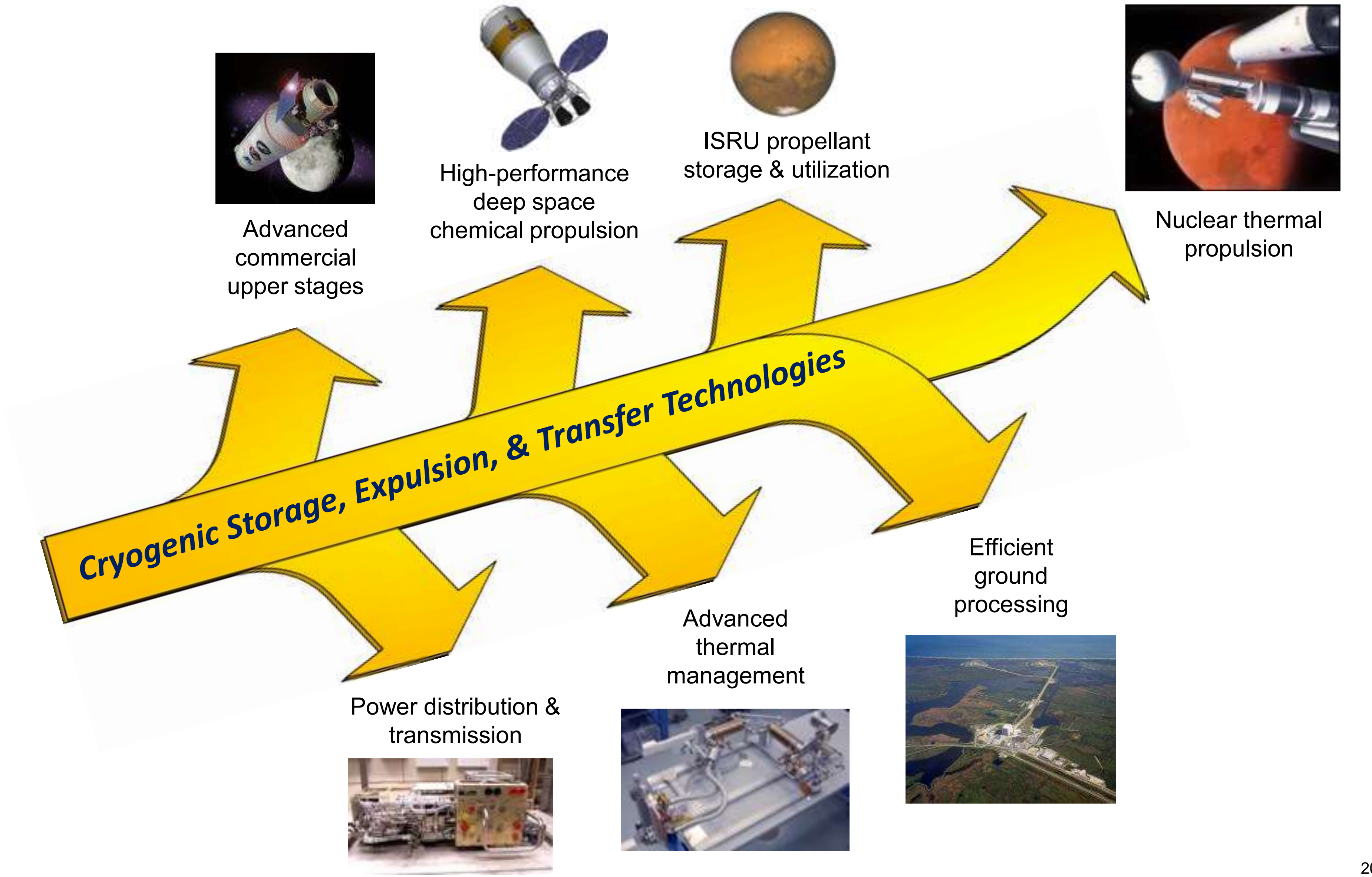
Space Technology Mission Directorate

Cryogenic Fluid Management Investments Overview

Jeffrey Sheehy, PhD
STMD Chief Engineer

18 Nov 2016

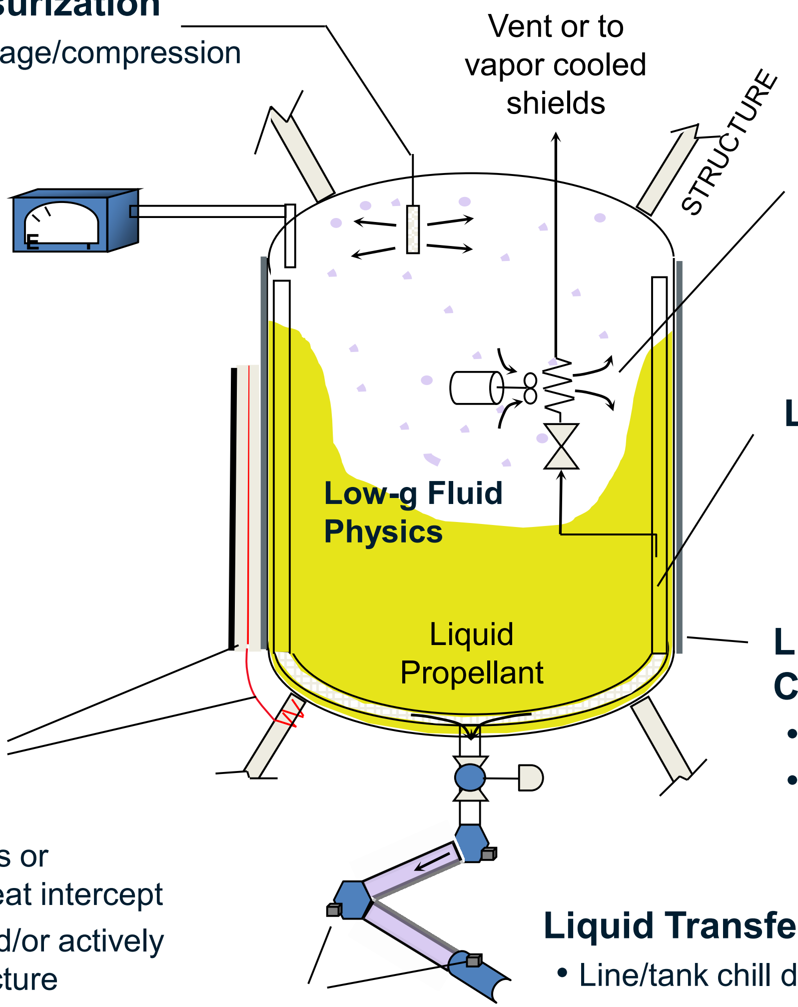
Cross-Cutting Benefits of Cryofluid Management Technologies



Major CFM Technology Elements

Pressurization
- Storage/compression

Propellant Gauging
- Propellant inventory
- Pressure / volume / temperature
- High accuracy micro-g techniques



Pressure Control
- Low-g mixing/venting (thermodynamic vent and heat exchanger)

Liquid Acquisition
- Capillary retention devices for micro-g
- Settling thrust

Lightweight Cryogenic Tank
- Metallic (Al-Li)
- Composite

Thermal Control
- Insulation
- Vapor-cooled shields or cryocooler-based heat intercept
- Low conductivity and/or actively cooled support structure
- Sun shades

Leak Detection

Liquid Transfer
- Line/tank chill down
- Pumps
- Leak-free couplings

Key CFM Technology TRL Assessments

Technology	TRL	Path to TRL 6
Tank MLI	5	Scale up to large implementations and perform ground or flight demo on integrated flight-like system
Low conductivity structure	5	Perform ground or flight demo on integrated flight-like system
90 K cryocooler (high thermal lift)	4	Scale up to large implementations and perform ground or flight demo on integrated flight-like system
Broad area cooled shield (tube on tank)	5	Perform **flight demo** on integrated flight-like system
Thermodynamic vent system	5	Perform **flight demo** on integrated flight-like system
Fluid mixing pump	4	Develop lightweight, low-voltage pump and perform **flight demo** in integrated flight-like system
Transfer line chill down in microgravity	5	Perform **flight demo** on integrated flight-like system
Pressurization system	5	Perform **flight demo** on integrated flight-like system
Valve	4	Develop low leakage valves and perform ground or flight demo on integrated flight-like system
Liquid acquisition device	5	Perform **flight demo** on integrated flight-like system
Radiofrequency mass gauge	5	Scale up to large implementations and perform **flight demo** on integrated flight-like system

CFM Technologies Requiring Flight Demonstration

Flight demonstration in the microgravity environment is required to validate several key CFM technologies:

- **Broad area cooled shield (tube on tank)**
  - Possible reliance on convection in tank / elimination of hot spots
- **Thermodynamic vent system**
  - Pressure rise rate / convection in tank and bubble dynamics during spray for destratification in microgravity
- **Transfer line chill down in microgravity**
  - Gravitational effects of flow boiling
- **Pressurization system**
  - Bubble formation and bubble dynamics due to injection in microgravity
- **Liquid acquisition device**
  - Operation in surface tension dominated environment with heat transfer
- **Mass Gauging**
  - Effects of fluid dynamics/curvature and ullage placement

TI&E Observations – July & Nov 2016

- **NASA needs cutting edge technologies to undertake its missions.**
  - Current missions are based on technologies developed through investments made over several decades.
- **In the timeframe FY2005-FY2009, technology budgets (basic research -$500M; applied research -$900M) were drastically reduced**
- **To reverse this decline, NASA established OCT (in 2010) and STMD (in 2013) and rebuilt the crosscutting technology program as well as made focused investments in technology development in HEOMD and SMD.**

TI&E Observations – July & Nov 2016 *(cont.)*

- **NASA management has done an excellent job of formulating the technology program and executing it, within annual budget constraints.**
  - Examples of past accomplishments (2010 to 2015): Composite Cryotank, Advanced Solar Arrays, High Power Electric Propulsion Thrusters, EDL including inflatable decelerators, High Performance Thermal Protection Systems, BEAM (Commercial Inflatable Habitat at ISS), and Small Spacecraft Technologies
  - Examples of upcoming accomplishments (2016 to 2020): Green Propellant Infusion Mission (GPIM), Deep Space Atomic Clock (DSAC), Solar Electric Propulsion demo, laser comm demos, RESTORE–L satellite servicing demo, in-space robotic manufacture & assembly, ISRU demo and Terrain Relative Navigation on Mars 2020
- **STMD reengaged the academic community in engineering research and technology development and has rekindled interest in NASA among students, especially at the graduate level.**
- **STMD has effectively used internal and external partnerships to mature and develop technologies.**

TI&E Concerns – July & Nov 2016

NASA has increased external and internal recognition for the importance of funding crosscutting technologies in STMD. However:

- **Technology budget priorities have been increasingly driven by factors external to STMD**
  - NASA priorities
  - Congressional direction
  - Increasing SBIR/STTR mandate
- **The consequence of this is canceled projects (EDL, CPST, LDSD, CEUS) and an inability to start high priority new activities that would give NASA technology options required for future missions *(see next chart).***
- **If NASA wishes to have a sustainable, crosscutting technology program, it has to find a more effective way of funding STMD working with its stakeholders.**
  - e.g. NASA could develop a long-term agency-wide policy for accommodating SBIR/STTR mandates and top line increases.

Thrust Areas Requiring Additional Investment

- **Lightweight Structures and Manufacturing**
  - Additional investment in materials, large space structures and manufacturing technology
  - Required to meet goals of reducing both mass and cost by 50%
- **Space Power and Propulsion**
  - Need to advance solar and nuclear power systems technology
  - Required for advanced propulsion systems (SEP and NTP) as well as surface power for Mars and deep space missions (e.g. Europa lander)
  - Also need continued investment in chemical propulsion/cryogenic fluids management (CFM)
- **Autonomy and Space Robotics Systems**
  - Need investments focused on human-robotic collaboration
  - Also should leverage external R&T for highly reliable, autonomous robotic/surface systems
- **Advanced Life Support and Resource Utilization**
  - Need to develop more comprehensive ISRU technology strategy/portfolio driven by architecture
  - STMD focusing on atmospheric ISRU and in-space/surface manufacturing
  - STMD will continue to deliver ECLSS component technologies to HEOMD/AES for system demonstration
  - Focus on next-generation, higher risk, higher payoff technologies
- **Maintain Early Stage** investment at ~10% of total STMD portfolio

Technology Needs to Support Proving Ground Missions for the Human Exploration of the Solar System

- We're looking forward to the HEOMD definition (in process) of the proving ground missions so that we can assess the technology investment/risk reduction required to support those missions.
- We were encouraged to see the agency continue to deepen its understanding and quantification of capability needs associated with human deep space missions, especially given the complex interactive nature of the systems required to enable the mission.
- We recognize the value of the close working relationship between HEOMD, SMD, and STMD personnel, particularly amongst discipline and integration experts.

TI&E Observations – November 2016 Technical Capability Assessment

- **TI&E concerned about generating and encouraging innovation within the agency.**
  - Impediments to innovation and actions to overcome them (OCE, OCT, STMD to report back to TI&E in Spring 2017).
- **TI&E believes still a lack of investment in foundational engineering sciences/research**
  - Technology: a solution that arises from applying the disciplines of engineering science to synthesize a device, process, or subsystem, to enable a specific capability.
- **TI&E believes Technical Capability Leadership will enable improved collaboration among centers**
  - Do need a set of standardized engineering tools across centers

TI&E Observations – November 2016
Cryogenic Fluid Management

- Cryogenic fluid management (CFM) technology development & demonstration has been and continues to be a significant emphasis area for STMD investment
- STMD is developing the key CFM technologies required for long-term space storage of cryogenic propellants
- STMD is performing extensive technology maturation and risk reduction testing for key CFM technologies, laying the groundwork for eventual mission infusion
- A system-level spaceflight demonstration that integrates the major CFM technologies will be necessary prior to mission infusion for cryogenic propulsion stages

TI&E Observations – November 2016

- **In-space Robotic Manufacturing and Assembly efforts - good example of a public-private partnership.**
- **Important STMD Milestones in FY 2017:**
  - DSAC/GPIM flight demonstrations (Sept 2017)
  - Small Spacecraft demos in FY 2017 (OCSD/ISARA/CPOD)
  - Laser Communication Relay Demo KDP-C
  - Solar Electric Propulsion PDR
  - RESTORE-L (Satellite Servicing demo) PDR
  - Initiate development of the High Performance Spaceflight Computer
  - Establishing Space Tech Research Institutes
- **TI&E is pleased NASA is incentivizing technology demonstrations on competitively selected science missions (e.g. deep space optical communications on upcoming Discovery mission).**
- **Committee encourages the continuation and enhancement of including incentives supporting tech demonstrations on future science missions**

TI&E Observations – November 2016

Small Spacecraft Technology Program study by IDA

- Independent assessment recommended to the STMD AA by TI&E
- Study to determine the appropriate focus for STMD's small sat investments moving forward
- Interim report from study team, Committee pleased with progress; final report due in February

SBIR/STTR – NASA and STMD should be commended for maximizing the returns to NASA, improving the support to small businesses; and broadening participation in the program. For example:

- Centralizing to STMD has led to more effective management of program
- STMD held a solicitation formulation workshop with MDs and Centers to develop more integrated solicitation technical topic areas to help proposers
- STMD held an Industry Workshop w/ prospective companies/bidders to help them understand NASA's requirements

BACK-UP

National Aeronautics and Space Administration

Space Technology Mission Directorate

Mars Architecture Technology Drivers Overview

Presented by:
William M. Cirillo & Kevin D. Earle
Systems Analysis & Concepts Directorate
NASA Langley Research Center

November 18, 2016

Major Human Mars Exploration Architectural Drivers

- **Goals & Objectives of the End State**
  - Number of Destinations
  - Satisfaction Date
  - Duration
  - Utilization Level & Capabilities
  - Number of Crew
  - Surface Systems
- **Pacing of Pathway**
  - Affordability
  - Safety
  - Sustainability
- **Transport of Cargo and Crew To & From Mars**
  - Earth-to-Orbit
  - In-Space Transportation
  - Entry, Descent, and Landing at Mars
  - Mars Ascent
- **Source of Provision of Commodities & Resources**
  - Water
  - Air & Other Gases
  - Logistics
  - Crew Time
  - Propellant
- **Keeping the Crew Healthy and Safe**
  - Mission Design
  - Radiation Mitigation
  - Microgravity Mitigation
  - Dust Protection & Mitigation

Current understanding of major architectural factors & considerations that drive benefit, cost, and risk.

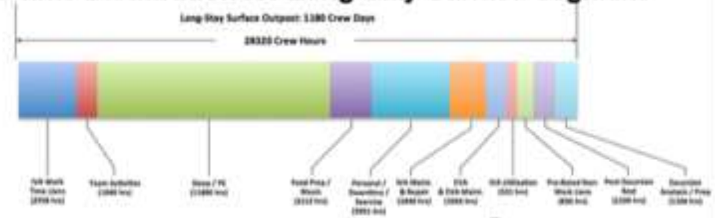
Trades and analysis are used to establish specific capability needs associated with these drivers.

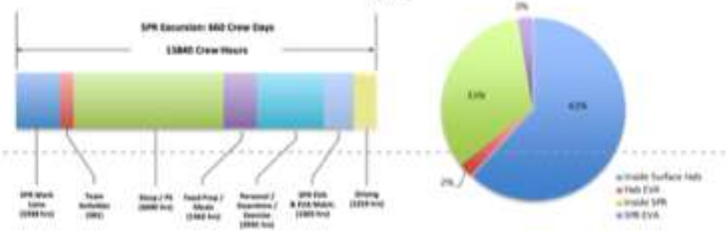
In turn, lower level system drivers will manifest themselves allowing for the evaluation of specific technology investments.

Characterization of Human Solar System Exploration Capability Needs

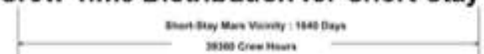
- Surface Long Stay
  - 8.5% of total surface time available for utilization
    Maximization of Small Pressurized Rover (SPR) excursion time eliminates most outpost EVA and IVA utilization
  - Long-stay architecture can accommodate a maximum of 22, 15-day excursions
  - Approximately 3.25 hours per day per crew of combined SPR EVA/Drive time:
    - Pressurized Rover drive and EVA may be directly traded
    - Virtually no Pressurized Rover IVA utilization
  - Exploration EVA limits Pressurized Rover drive time
  - Decreased exercise requirements due to hypo-gravity environment and increased surface EVA is primary enabler of additional utilization opportunity

Crew Time Distribution for Long Stay Surface Segment





Crew Time Distribution for Short Stay Surface Segment



- Important to perform systems analysis to identify and assess capability needs to a level sufficient to evaluate and trade technology options.
- Important to understand needs across HEOMD, SMD, and commercial to allow formulation of high value technology portfolios through identification of cross-cutting technology solutions.

Draft 2017 NASA STIP

- **Key consideration in this STIP**

- Effort began in early FY2016,
  - Started from current roadmaps, linked technology solutions to reference missions,
  - Factored in NRC, Mission Directorates and offices priorities,
  - Examined combination of weighing factors reflecting space policy, strategic plan,
  - Implemented a custom, formal multi criteria decision making process,
  - Recommended a 70% critical – 20% essential – 10% complementary balance to the investment portfolio.

- **What is new in this STIP (compared to 2012 version)?**
  - Linked to the NASA Strategic Plan with top-down and bottom-up assessment
  - Updated roadmaps (2015),
    - "Included" Aeronautics roadmaps,
  - NTEC initially involved, setting technology policy, prioritization, strategic investments.

- **Status of the STIP development**
  - Initial draft developed, awaiting NTEC/STIP leadership team feedback.
  - ID'd 378 critical technologies at the 4th roadmap level (technology candidates)
    - This process under review

Draft 2017 NASA STIP: Next Steps

- Start from **NRC 2016 report,** factor in **STIP 2017** draft
- Sort out fundamental assumption differences and impact on different prioritizations
- Re-visit 70%/20%/10%, consider alternatives, seek consensus
- Factor in Aero so as to highlight cross-cutting technologies
- Focus on reflecting
  - MD priorities
  - Cross-cutting technologies
  - Lead-collaborate-watch-park classification
- Run a 2-3 days workshop in December
- Facilitated by CTC, OCT with technical/analysis support by Tauri Group