National Aeronautics and
Space Administration

Technology, Innovation & Engineering Committee Report NASA Advisory Council

Presented by:
Dr. Bill Ballhaus, Chair

March 31, 2017

www.nasa.gov/spacetech

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 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.**

NASA Transition Authorization Act of 2017

Law authorizes a Space Technology Program – The bill formally authorizes Space Technology, an authorization that was not included in the FY 2010 Authorization Act.

SEC. 702. SPACE TECHNOLOGY PROGRAM.

(a) SPACE TECHNOLOGY PROGRAM AUTHORIZED.— The Administrator shall conduct a space technology program (referred to in this section as the “Program”) to research and develop advanced space technologies that could deliver innovative solutions across the Administration’s space exploration and science missions.

TI&E Committee Meeting Attendees March 28, 2017

- Dr. William Ballhaus, Chair
- Mr. Gordon Eichhorst, Aperios Partners, LLP
- Dr. Kathleen Howell, Purdue University
- Mr. Michael Johns, Southern Research Institute
- Dr. Matt Mountain, Association of Universities for Research in Astronomy
- Mr. David Neyland
- Mr. Jim Oschmann, Ball Aerospace & Technologies Corporation
- Dr. Mary Ellen Weber, Stellar Strategies, LLC

TI&E Committee Meeting Presentations March 28, 2017

- Space Technology Mission Directorate Update
  - Mr. Stephen Jurczyk, STMD Associate Administrator
- Space Technology Research Institutes Overview
  - Dr. Jay Falker, STMD Early Stage Portfolio Executive
- Entry, Descent and Landing (EDL) Update
  - Dr. LaNetra Tate, STMD Program Executive and Ms. Michelle Munk, EDL Principal Technologist
- Update on STMD Strategic Implementation Plan
  - Ms. Trina Chytka, Director of STMD Strategic Integration & Planning (Acting) and Mr. William Cirillo, NASA Langley Systems Analysis and Concepts Directorate
- NASA's Barriers to Innovation & Chief Technologist Update
  - Mr. Douglas Terrier, Chief Technologist (Acting)
- Small Spacecraft Technology Study Final Report
  - Dr. Bhavya Lal, IDA Science and Technology Policy Institute

National Aeronautics and
Space Administration

Space Technology Research Institutes (STRI)

Overview for the NAC TI&E Committee

Dr. Jay Falker, STMD
Early Stage Portfolio Executive

28 March 2017

Space Technology Research Institutes 2017: Key Features and Award Information

Key Features

- **Empowered** university-led team
- Guiding Vision with ***resilient*** research strategy
- Specific research objectives with **credible expected outcomes** in next 5 years
- **Multidisciplinary** research program
- **Leveraging** SOA capabilities (likely created by OGA investments)
- Talented, **diverse**, cross-disciplinary, fully-integrated team
- Low to mid TRL
- **Innovative** technical approaches
- **Publications** (many) and **open source** access to results

Award Information

- Expected duration: **5 years**
- Award amount up to **$3M per year** ($15M over 5 years)
- Institutes expected (and *empowered*) to implement their own review processes
- NASA oversight – annual reviews and brief quarterly status reports
- Award instrument: grants

CUBES: **Bio-Manufacturing for Deep Space Exploration**

US COMP: **Computationally Accelerated Materials Development for Ultra High Strength Lightweight Structures**

National Aeronautics and
Space Administration

Space Technology Mission Directorate

Entry, Descent and Landing (EDL) Strategy and GCD Program Investments

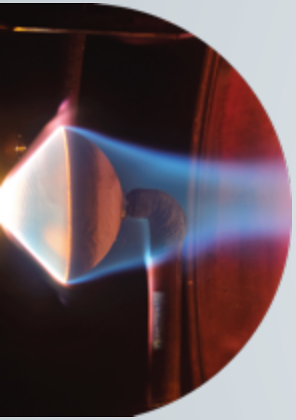
Presented by:
Michelle M. Munk
STMD Principal Technologist for EDL

LaNetra C. Tate, Ph.D.
Program Executive, Game Changing Development Program

Briefing to the NAC TI&E Committee

March 28, 2017

Entry Descent and Landing Systems



Description

Enable more capable future robotic and exploration missions to land on various bodies such as the Mars, moons, and asteroids. Robust and highly reliable solutions need to be developed that target higher landed mass, landing site elevations, and precision landings.

External Application

Returning commercial assets from space

Quantifiable Objectives:

- Land 20 Metric Tons on Mars Surface
- Convective heating capability >5000 W/cm2 and 5+ atm pressure
- Robotic Mars: 10-100 m landing footprint
- EDL modeling: reduce uncertainties by >50%, improve runtimes by 100%

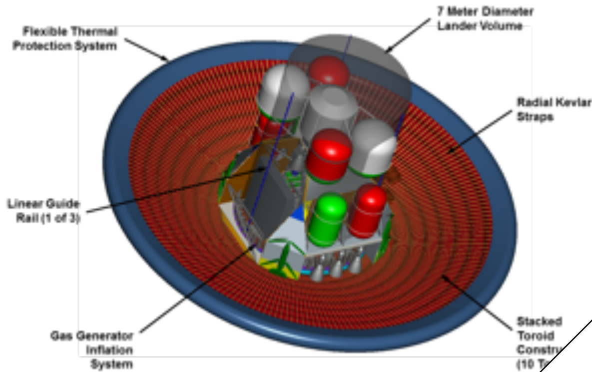
Current Portfolio

- Entry Systems Modeling
- Mars Entry Descent & Landing Instruments (MEDLI 2)
- Thermal Protection Systems Materials
- Terrain Relative Navigation (TRN)
- Propulsive Descent Technologies
- Hypersonic Inflatable and Deployable Aerodynamic Decelerator

Entry Technologies Considered for Human Mars Missions

Inflatable

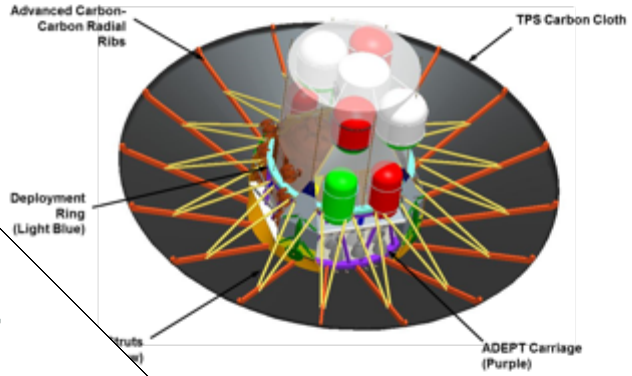
HIAD – Hypersonic Inflatable Aerodynamic Decelerator



Deployable

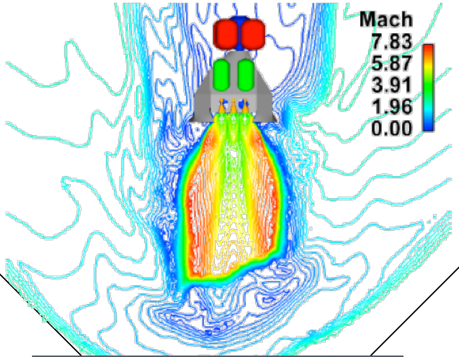
ADEPT – Adaptable Deployable Entry and Placement Technology

16 Rib Point Design Configuration
(Perimeter Segments not Represented)



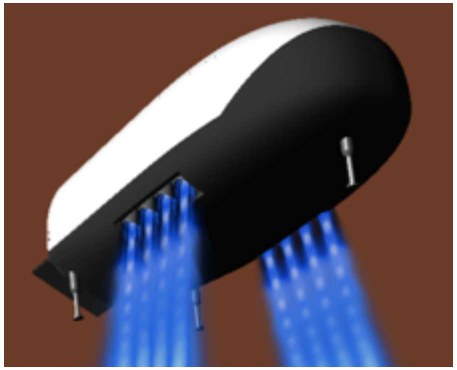
Supersonic Retro-Propulsion

Common to All



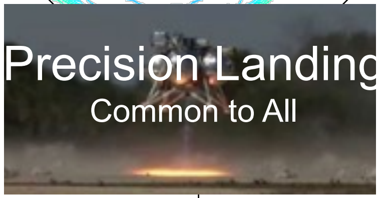
Mid L/D

Rigid Structure



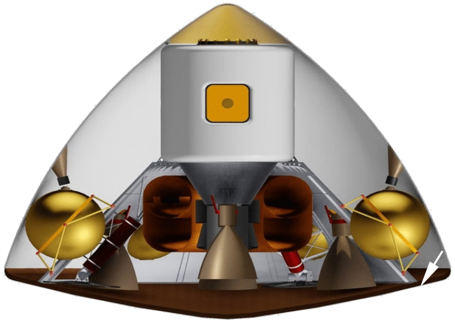
Precision Landing

Common to All



Capsule Concept

Rigid Structure



All configurations are conceptual

Update on STMD Strategic Implementation Plan

Presented by:
Dr. Trina Chytka, Director, STMD Strategic Integration and Planning (Acting)

William M. Cirillo, Kevin D. Earle, & Andrew C. Owens
Systems Analysis & Concepts Directorate
NASA Langley Research Center

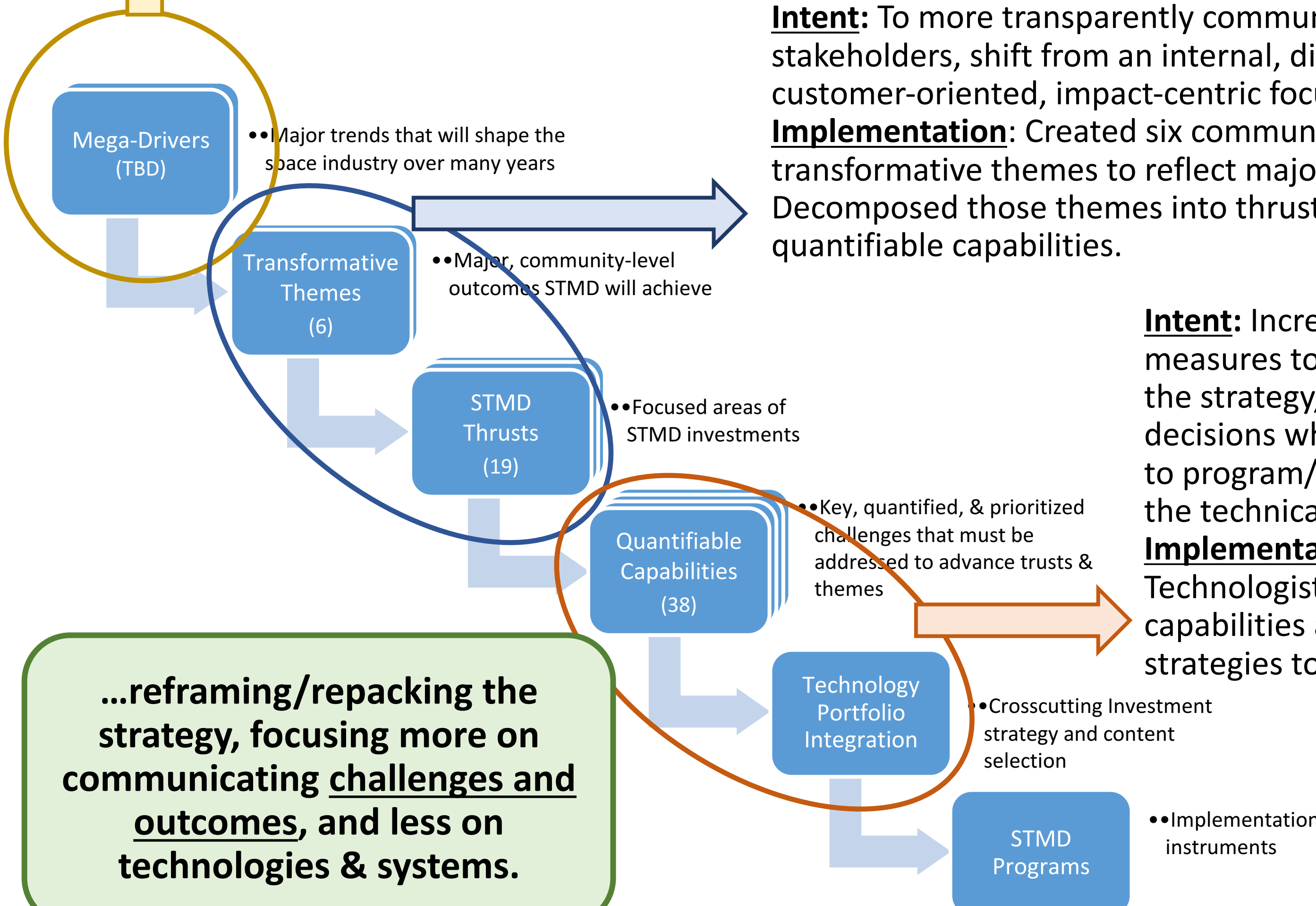
March 28, 2017

Revised STMD Strategic Framework

Intent: Derive the framework directly from stakeholders (HEOMD, SMD, other government agencies, & U.S. industry).
Implementation: Identify mega-drivers through discussions with customers, market research, and analysis.

Intent: To more transparently communicate impacts to customers & stakeholders, shift from an internal, discipline-centric focus to a customer-oriented, impact-centric focus.
Implementation: Created six community-level, outcome-centric transformative themes to reflect major thrusts of STMD portfolio. Decomposed those themes into thrusts to serve as a bridge to the quantifiable capabilities.

Intent: Increase use of quantifiable measures to more easily operationalize the strategy, increasing traceability of decisions while providing clearer guidance to program/project/line management & the technical workforce.
Implementation: STMD Principle Technologist (PTs) developed quantifiable capabilities and corresponding investment strategies to inform portfolio formulation.



…reframing/repacking the strategy, focusing more on communicating challenges and outcomes, and less on technologies & systems.

Quantifiable Capabilities

Increase use of quantifiable measures to make the strategy easier to operationalize, increasing traceability of portfolio formulation decisions while providing clearer guidance to and empowering program/project/line management & the technical workforce.

- Implementation:
  - STMD Principle Technologist (PTs) developed quantifiable capabilities and corresponding investment strategies to inform portfolio formulation.
  - Prioritized performed by STMD Senior Leadership
- Use:
  - Focuses STMD resources on achieving the Quantifiable Capability
  - Messaging internally and externally on what STMD is pursuing
  - Informing Program investment decisions
- Example – QCs in EDL:

Entry, Descent, & Landing
- → High Mass to Mars Surface
- → Precision Landing and Hazard Avoidance
- → EDL Data Return and Model Improvement
- → High-Speed Planetary Probes / Earth Return Capsules

Transformative Themes and Associated Thrusts

Expand Utilization of Near-Earth Space

- Provide safe and affordable routine access to space
- Enable extension, reuse, and repair of near-Earth assets
- Expand near-Earth infrastructure and services to support human and science exploration beyond low Earth Orbit

Develop Efficient & Safe Transportation Through Space

- Provide cost-efficient, reliable propulsion for long duration missions
- …

Increase Access to Planetary Surfaces

- Safely and precisely deliver humans & payloads to planetary surfaces
- …

Enable Humans to Live and Explore on Planetary Surfaces

- Increase crew effectiveness and access to diverse, high-value sites
- …

Enable Next Generation of Science Beyond Decadal

- Expand access to new environments and measurement platforms to enable high-value science
- …

Grow & Utilize the U.S. Industrial and Academic Base

- Open and foster new space markets for U.S. commerce
- …

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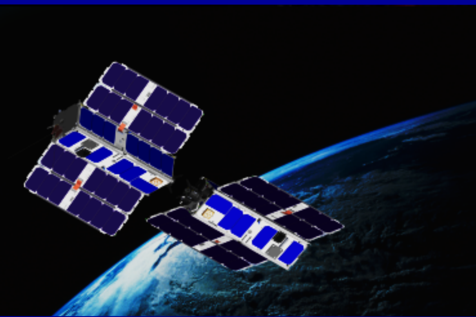
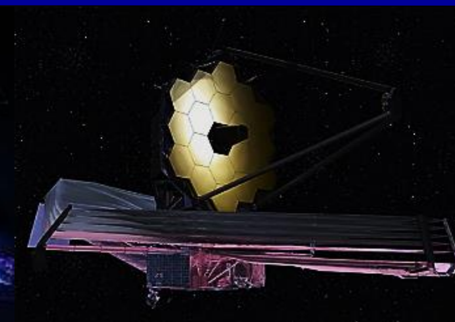





Innovation at NASA
Chief Technologist's Update to The NASA Advisory Council

Dr. Douglas Terrier
Chief Technologist (Acting)

March 28, 2017

NASA Advisory Council, November 2016

- How do we promote innovation?
- How do we address barriers to innovation?

OCT will brief the next NAC TI&E meeting on NASA's initiatives to address impediments to innovation

Summary

- NASA's Office of the Chief Technologist (OCT) broadly engaged Mission Directorates and Centers at various levels to identify barriers to innovation
- Barriers were mapped to cross-cutting themes and potential solutions developed
- Cross-Agency effort evaluated and deployed potential solutions
- A-suite level review evaluated progress and assigned actions to address impediments and formalize innovation initiative
- Communicating effort across the United States Government (USG) as the Federal Center for Excellence in Collaborative Innovation (CoECI), and with private sector.

OCT is currently assessing NASA's innovation efforts across the Agency and developing a framework to leverage existing resources and promote enterprise level management while fostering a culture of innovation

NASA Innovation Surveys

- Internal survey results from 2011 showed desire for improved innovation culture:

93% - I am constantly looking for ways to do my job better

Barriers Describe a Gap

- Lack of Opportunity
- Risk-Averse Culture
- Process Overload
- Instability

- Project (Short-Term) Focus
- Communication Challenges
- Organizational Inertia
  - Silos & Unwillingness to Change

74% - I feel encouraged to come up with new and better ways of doing things

61% - Believe creativity and innovation are rewarded

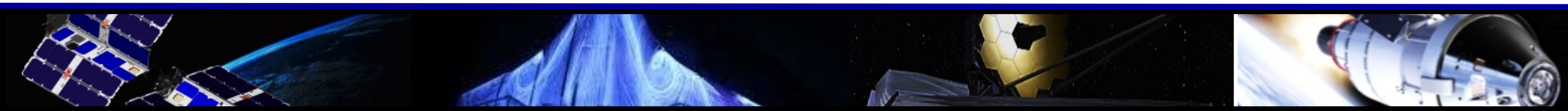
Source: OCT 2011 survey results

- NRC Review on NASA (2011)
  - NASA's technology base is largely depleted
  - Success will depend on advanced technology developments

- NASA innovation culture is improving *(2017 Partnership for Public Service report)*
  - #1 in Innovation in large Federal Government agencies
  - Best in government in adopting best commercial practices

Barriers to Innovation at NASA

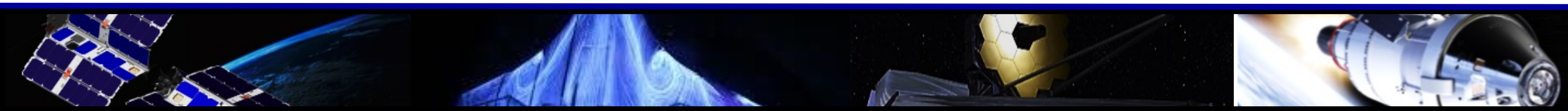
Barrier	Description
Risk-averse culture	• Management/workforce conservatism and oversight bodies drive costs and create more incremental steps
Short-term focus	• Immediate mission needs (for example, meeting level 1 requirements) often must take priority over development of future capabilities
Instability	• Changes in decisions and direction set by external stakeholders as well as tactical decisions have dried the innovation pipeline and led to a cycle of technology start/stops
Lack of Opportunity	• Fewer flight opportunities have reduced available pathways for infusion of innovations. Technology demonstrations historically come and go, yet have spurred some of the revolutions in NASA history
Process Overload	• Excessive administrative burdens can stagnate innovators; process owners have become gatekeepers instead of enablers
Communication Challenges	• Organizational silos, ‘not invented here’ thinking, and lack of commonality in IT and communication technologies for linkage
Organizational Inertia	• Cultural tendency to stay the course and a lack of trust often portray innovation as a threat; need to balance the risk with reward



OCT is Champion for Innovation at NASA

OCT is NASA's champion for innovation and is coordinating with Mission Directorates and Centers to drive NASA's innovation culture

- OCT is developing an innovation framework to integrate and manage innovation activities across the Agency
  - Vicki Crisp, OCT, executive champion for Agency innovation activities
  - Developing a strategic plan for innovation activities, to institutionalize processes and best practices for innovation at NASA
  - Working with senior leadership to address Agency-level constraints
  - Coordinating across Mission Directorates through NASA Technology Executive Council (NTEC)
  - Cooperating across USG through Interagency S&T Partnership Forum
  - Coordinating cohesive Center initiatives through Center CT council
  - Developing an Innovation Portal to augment NASA SOLVE
  - Refining current innovation activities to drive more return to participants
- Our challenge is to bring all NASA's innovation activities together into a self-sustaining corporate innovation endeavor



IDA SCIENCE AND TECHNOLOGY POLICY INSTITUTE

Trends in Small Satellite Technology and the Role of the NASA Small Spacecraft Technology Program

Final Update to the NASA Advisory Committee
Technology, Innovation and Engineering Committee

March 28, 2017

Bhavya Lal, Asha Balakrishnan, Alyssa Picard, Ben Corbin,
Jonathan Behrens, Ellen Green, Roger Myers

Reviewers: Brian Zuckerman, Mike Yarymovych, Iain Boyd, Malcolm MacDonald

Project Goal

Given investments outside STMD, and NASA's mission needs, what is the "the appropriate, discriminating role for STMD vis-à-vis all the other organizations that are developing small satellite technology?"

Overall Approach

- Examined smallsat developments
  - State-of-the-art and activities outside STMD
  - Evolution of the ecosystem: players and markets
  - Drivers of future activities: infrastructure, policies, investment
- Analyzed STMD's current and emerging smallsat portfolio
- Identified NASA's small spacecraft needs, both user driven (tech pull) and technology driven (tech push)
- Identified gaps and made recommendations

- Scope
  - STMD's Small Spacecraft Technology Program (SSTP) supplemented by other STMD efforts
  - Did not conduct an evaluation
    - No comment on adequacy of funding levels
- Definition of a small spacecraft or smallsat
  - Considered several metrics – mass, cost, innovation approach ("lean satellite")
  - Settled on mass with upper limit ~200 kg
    - With exceptions up to 500 kg as needed

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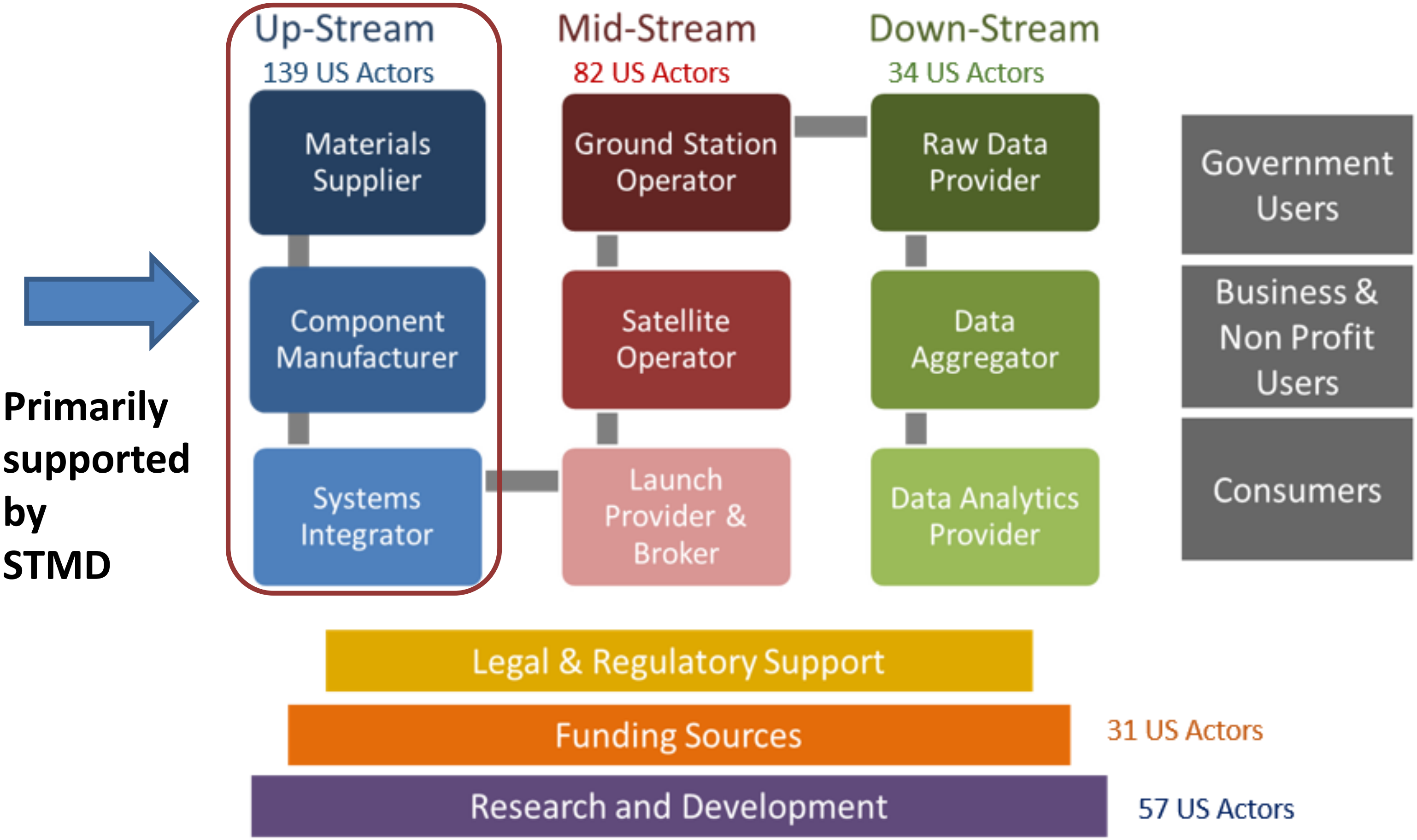
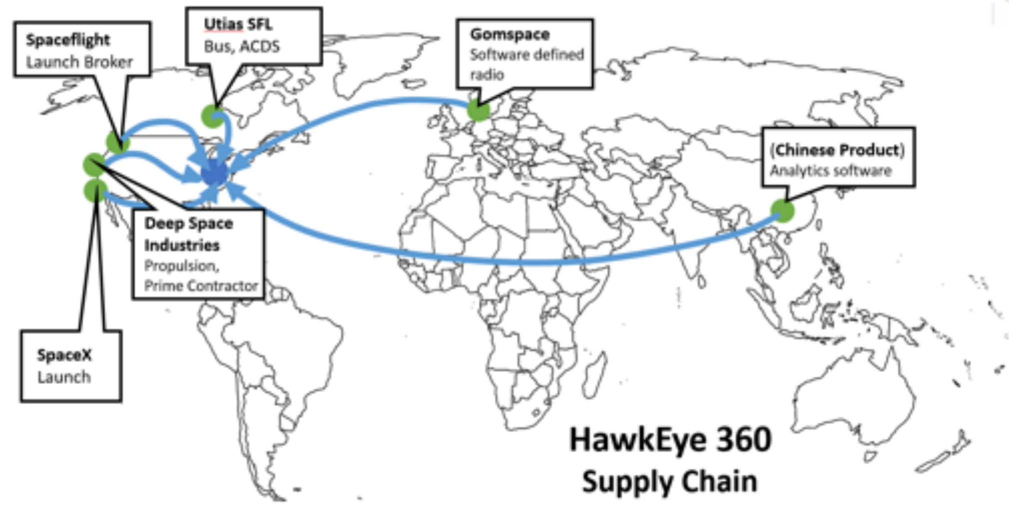
STMD's Smallsat Programs Support Upstream Activity in the Smallsat Ecosystem

Primarily supported by STMD



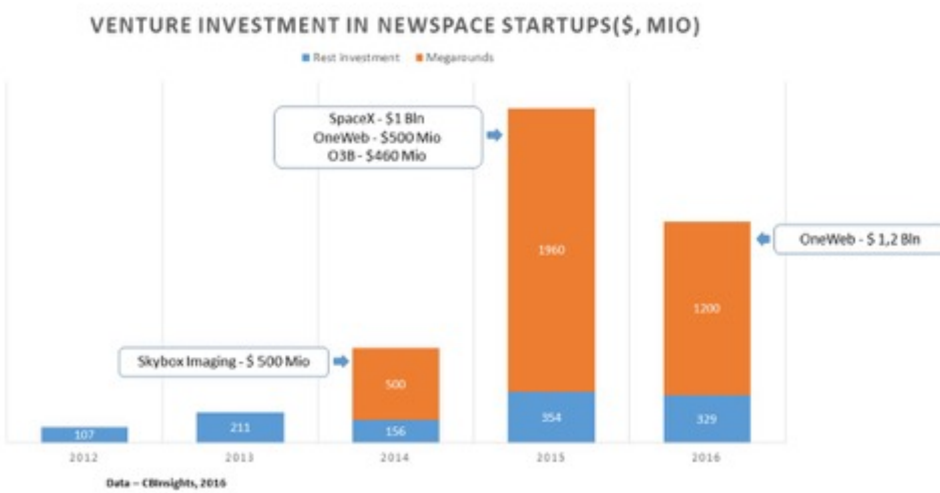
Sector is Globalized and International

- Companies have global supply chains and customers
- Anyone (government, bank) can purchase turnkey service
  - Surrey Satellite Technology Ltd. (SSTL) designed, built, and launched a constellation of Earth observation satellites for their China-based client Twenty-First Century Aerospace Technology



Private Funding for Smallsats Exceeds Government Funding

- Private funding may exceed government funding by an order of magnitude or more
  - Nearly twice as much venture capital was invested in space in 2015 than the previous 15 years, combined
  - Non-traditional investors – Coca Cola in OneWeb



Company	Venture Capital and Equity Financing through 2016 (Millions)
OneWeb constellation	$1,719
SpaceX constellation	$1,185
Planet constellation	$171
Kymeta	$144
Spire	$67
Spaceflight Industries/ Blacksky	$45
Astroscale	$43

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Summary: Findings/Conclusions

- STMD is one of many investors in the smallsat ecosystem; its funding may be dwarfed by other public and private sources by 1-2 orders of magnitude
  - STMD is one of a small number of government organizations that has the mandate to support upstream, far-term, high pay-off platform technologies
  - Private funding focuses on operations and near-term almost-mature technologies *or* on high pay-off technologies that will <u>remain proprietary</u>
- STMD is supporting what stakeholders view as the most important technologies (systems/constellation, propulsion, communication) but not industrial commons to the degree needed
- Primary challenges faced by STMD are not related to technology areas selected but to lack of effective communication and coordination with stakeholders

Summary: Recommendations

- STMD could add funds to program to increase focus on deep space systems and avionics, launch and debris mitigation and control technologies, as well as support of industrial commons
- Smallsat programs in STMD must keep their unique value in the ecosystem, and maintain independence and a degree of separation from users (to prevent short-termism)
- Better communication and coordination would require:
  - A mission statement [(1) what is the basic purpose of SSTP; (2) what makes it unique; (3) who are the principal customers; and (4) how are priorities determined] and continual communication
  - A transparent framework for decisionmaking that explains how each project fits with mission
  - Transition partners to promote infusion, even for push technologies – another way to ensure greater transparency/formality of communication
  - Program autonomy, metrics for program success, and continual evaluation to ensure course correction

Space Technology Highlights

Important STMD Milestones in FY 2017:

- DSAC/GPIM flight demonstrations awaiting launch on STP-2 (Dec. 2017)
- Small Spacecraft demos ready for launch in FY 2017 (OCSD/ISARA/CPOD)
- Laser Communications Relay Demo KDP-C – completed
- Solar Electric Propulsion PDR
- Restore-L (Satellite Servicing demo) PDR
- Initiate development of the High Performance Spaceflight Computer Processor – completed (awarded contract to Boeing)
- Establishing Space Tech Research Institutes – completed (announced selectees)

Space Technology Highlights

Additional STMD Milestones:

- Flight Opportunities added Blue Origin as new flight provider
- Independent review of Centennial Challenges program (TI&E will be briefed next meeting)
- Selected 8 awardees for Tipping Point solicitation –
    - Small Launch Vehicle Technology and Small Spacecraft Demo Missions
- Deep Space Optical Communications transitioning to TDM, flying on Science Discovery Psyche mission.
- SBIR holding second industry day in June
- SEXTANT/NICER launching in May
- COBALT flights with Masten to advance autonomous landing and hazard avoidance technology
- 3-D Printed Habitat Challenge – 25+ competitors for Phase I
- ADEPT pre-ship review in June and flight test launching in November on UP Aerospace SpaceLoft sounding rocket

ADEPT
SR-1 Animation

BACK-UP

0007: Center for the Utilization of Biological Engineering in Space (CUBES)

(Adam Arkin, UC Berkeley)

Center for the Utilization of Biological Engineering in Space (CUBES) [Version 2]

Vision Statement and Research Objectives: CUBES will

- create an integrated, multi-function, multi-organism biosystem;
- demo continuous and semiautonomous biomanufacture of fuel, materials, pharmaceuticals, and food in Mars-like conditions;
- conduct multidisciplinary research in: artificial photosynthesis, a biological Haber-Bosch process, CO_2 reduction to other C1 compounds, ammonia nitrification, perchlorate reduction, the generation of C1/C2/C3 and nitrous oxide fuels, biopolymer production and use in additive manufacturing devices, microbe and plant pharmaceutical synthesis, increased food production by plants and microbes, organism extreme-environment cultivation and testing in a Mars-environment simulator, and overall biosystem integration, seeding and testing.

Team:

Adam P. Arkin, PI, UC Berkeley
Amor A. Menezes, Co-I (Science PI), UC Berkeley
Craig S. Criddle, Co-I (Institutional PI), Stanford U
Karen A. McDonald, Co-I (Institutional PI), UC Davis
Lance C. Seefeldt, Co-I (Institutional PI), Utah State U
Aaron J. Berliner, Other Professional, Autodesk
Bruce Bugbee, Co-I, Utah State U
Christopher J. Chang, Co-I, UC Berkeley
Douglas S. Clark, Co-I, UC Berkeley
Devin Coleman-Derr, Co-I, UC Berkeley
Kalimuthu Karuppanan, Co-I, UC Davis
Somen Nandi, Co-I, UC Davis
Robert M. Waymouth, Co-I, Stanford U
Peidong Yang, Co-I, UC Berkeley

Earth Analog Benefits: These include

- bioengineered organism utilization in deserts, ice sheets, remote/rural civilization, and other environments, thereby "going beyond" the bioreactor and converting scarce resources to useful products while in similarly extreme environments;
- carbon capture that reduces greenhouse gases, combats climate change, and converts C1 intermediates to fuels, chemicals, etc.;
- food/water production and waste/nutrient recycling to address famine, drought, global warming, and burgeoning populations;
- on-demand pharmaceutical production, medical diagnostics, and cell-based treatments/therapeutics that can lead to personalized medicine, targeted delivery of clinical treatments, rapid and decentralized responses to biosecurity threats, emergency responses to catastrophic medical failures, etc.

(This quadrant intentionally blank – for evaluation notes)

Institute for Ultra-Strong Composites by Computational Design

US COMP

Vision statement

Serve as a focal point for partnerships between NASA, other agencies, industry, and academia to: (1) enable computationally-driven development of CNT-based ultra high strength lightweight structural materials within the Materials Genome Initiative (MGI) paradigm and (2) expand the resource of highly skilled engineers, scientists and technologists in this emerging field

Research objectives

- Develop a novel ultra high strength lightweight structural material for use in deep space exploration vehicles
- Establish a new computationally-driven material design paradigm for rapid material development
- Develop modeling, processing, and testing tools and methods for carbon nanotube based material systems

Leadership team

Greg Odegard, Michigan Tech, Director, SDT Team Leader
Richard Liang, Florida State, Deputy Director, MST Team Leader
Mike Czabaj, University of Utah, TCT Team leader
John Hart, Massachusetts Inst of Tech, MMT Team leader

University members

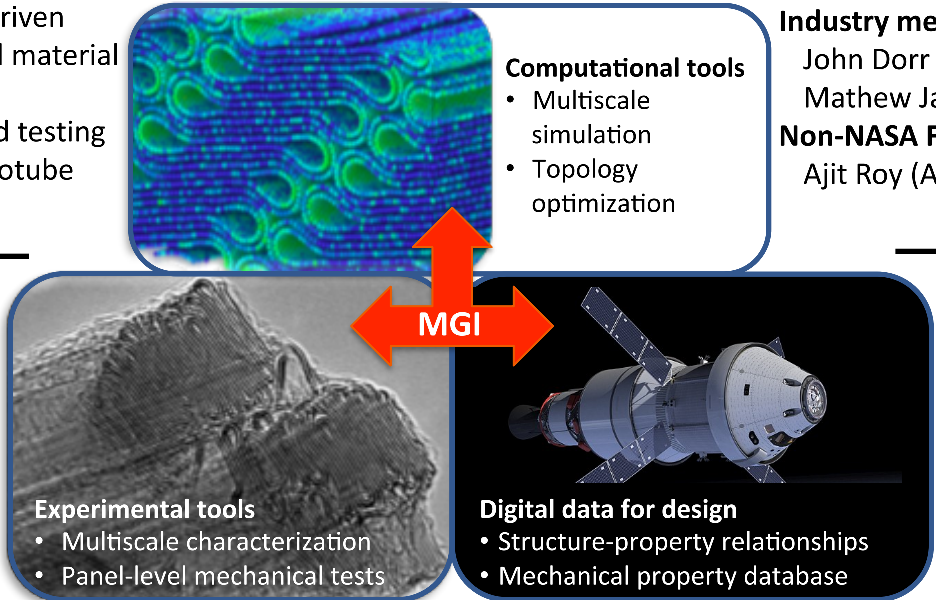
Dan Adams, Tarik Dickens, Traian Dumitrica, Susanta Ghosh, Jamie Guest, Ibrahim Guven, Ayou Hao, Hendrik Heinz, Julie King, Satish Kumar, Okenwa Okoli, Ravi Pandey, Jin Gyu Park, Trisha Sain, Ashley Spear, Adri van Duin, Brian Wardle, Chad Zeng

Industry members

John Dorr (Nanocomp)
Mathew Jackson (Solvay)

Non-NASA Federal lab partner

Ajit Roy (Air Force Research Lab)



Approach

The institute is organized into four teams that will work work collaboratively to achieve the research objectives:

- The Simulation and Design Team (SDT) will establish structure-property relationships and new material design methodologies
- The Materials Synthesis Team (MST) will pioneer precise patterning synthesis techniques and optimize interphases for material performance enhancement
- The Material Manufacturing Team (MMT) will focus on the scale-up manufacturing of highly aligned and concentrated CNT composites
- The Testing and Characterization Team (TCT) will conduct multiscale characterization of the CNT composites and develop new test methodologies to explore this new class of materials

(This quadrant intentionally blank – for evaluation notes)

Transformative Themes and Associated Thrusts

Expand Utilization of Near-Earth Space

- Provide safe and affordable routine access to space
- Enable extension, reuse, and repair of near-Earth assets
- Expand near-Earth infrastructure and services to support human and science exploration beyond low Earth Orbit

Develop Efficient & Safe Transportation Through Space

- Provide cost-efficient, reliable propulsion for long duration missions
- Increase effectiveness and applicability of current propulsion options
- Enable significantly faster, more efficient deep space missions
- Provide efficient and safe in-space habitation

Increase Access to Planetary Surfaces

- Safely and precisely deliver humans & payloads to planetary surfaces
- Increase access to high-value science sites across the solar system
- Provide efficient, highly-reliable Earth sample return reentry capability

Enable Humans to Live and Explore on Planetary Surfaces

- Enable humans to survive
- Provide efficient/scalable infrastructure to support exploration at scale
- Increase crew effectiveness and access to diverse, high-value sites

Enable Next Generation of Science Beyond Decadal

- Expand access to new environments and measurement platforms to enable high-value science
- Enable substantial increases in the quantity and quality of science data returned
- Enable high-power measurements for long duration science missions

Grow & Utilize the U.S. Industrial and Academic Base

- Provide NASA technology to grow the U.S. industrial & technology base
- Open and foster new space markets for U.S. commerce
- Drive U.S. innovation & expand opportunities to achieve the NASA dream