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Meeting Minutes

G. Michael Green, Executive Secretary

William F. Ballhaus, Jr., Chair

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Technology, Innovation, and Engineering Committee
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Elizabeth Sheley

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Welcome and Overview of Agenda/Logistics
Mr. G. Michael Green, Executive Secretary of the NASA Advisory Council (NAC) Technology, Innovation, and Engineering (TI&E) Committee, welcomed the members and reviewed the meeting agenda. The Committee agreed to look at dates in late March through mid-April for the next meeting.

Opening Remarks
Dr. William Ballhaus, TI&E Chair, reviewed his charts of the TI&E recommendations to the full NAC from July 2016. The intent behind the creation of the Space Technology Mission Directorate (STMD) was to rebuild NASA's crosscutting technology program. However, funding has been insufficient despite the efforts of the NASA front office, and there are liens against the budget.

Technology has not been a high priority for NASA, and the budget has been reduced by both Congressional direction and the Small Business Innovation Research (SBIR) / Small Business Technology Transfer (STTR) program mandates resulting in the delay or cancellation of some major technology demonstrations. There is a need for an urgency argument, which reflects the lack of a plan. Dr. Ballhaus identified five thrust areas requiring additional investment: lightweight structures and manufacturing; space power and propulsion; autonomy and space robotics systems; advanced life support and resource utilization; and maintenance of early stage technology development. TI&E will keep advancing these points with the new administration, but will need mission pull as well.

Dr. Ballhaus reported that Mr. William Gerstenmaier, Associate Administrator (AA) of the Human Exploration and Operations Mission Directorate (HEOMD), took these recommendations to heart. He therefore decided to put technology and mission risk reduction into a series of risk reduction missions, or proving ground missions, that would provide the urgency argument and give STMD the mission pull.

Space Technology Mission Directorate Update
Mr. Stephen Jurczyk, STMD AA, reported that the Directorate has made a lot of progress recently in the proving ground missions, with an initial identification of the major technology capabilities that are needed. There has been some work on timelines, as well, resulting in a high-level schedule and some notional budgets. This work should provide the urgency arguments TI&E seeks. STMD is currently getting external input on laying out the missions, and is making progress toward determining the Technology Readiness Level (TRL) targets

and drivers. That should set priorities and dates. Most of the big projects will be Technology Demonstration Missions (TDMs).

Dr. Ballhaus wondered if the work might align with the president-elect's campaign theme. Mr. Jurczyk said that STMD was created to be cross-cutting, enabling technologies for human exploration, science, and more, as well as defense and commercial interests. The focus has been on having a broad impact, especially with commercial enterprise. Beyond the International Space Station (ISS), NASA will need commercially provided Low-Earth Orbit (LEO) capabilities. He is always meeting with commercial interests of all sizes to get their input. It has been useful to have public/private partnerships through the Tipping Point solicitation, which seeks specific technologies and small launch vehicle capabilities, as well as the Catalyst Announcement of Opportunity (AO). STMD encourages companies to respond to Requests for Information (RFIs). From those, the Directorate can pick the technology areas for public/private partnerships.

Dr. Ballhaus asked about feedback from industry regarding the value of NASA's technology investments. Mr. Jurczyk replied that STMD gets feedback from the companies when they meet. The companies take advantage of investments made over the years, so the benefits do not always appear as direct. NASA does have some institutional capabilities for things like Entry, Descent, Landing (EDL). It would not be reasonable for companies to recreate things the Agency has built up over decades. STMD's stakeholders in Congress value the input from companies, and there has been more of that in the last year or so. Congress has noticed this, and the feedback has been positive. What STMD does has to be strategically important to them to enable the companies to develop systems further down the road. They have articulated that fairly well.

Priorities have included a more robust investment plan for technology thrust areas, which has been largely successful. Mr. Jurczyk will discuss that at the next TI&E meeting. STMD created some strategic themes around expanding certain areas in human exploration and science. The Principle Technologists (PTs) now have a stronger role in these, and each PT has developed an investment strategy. This will help STMD articulate its priorities and guide investment. That will also be on the agenda for the next meeting.

Mr. Jurczyk gave examples of advances in some projects, such as the Deep Space Atomic Clock (DSAC), which is critical for deep space navigation and communications, as well as the next generation of GPS, which will be an Air Force priority. Deep Space Optical Communications (DSOC) is being transitioned to a flight project in TDM. For the Discovery program in the Science Mission Directorate (SMD), STMD offered the Principal Investigators (PIs) an incentive for using the technology, and three out of five took it. This adds little risk to them while helping STMD to demonstrate the technology.

SMD is looking at using constellations of small satellites (smallsats) and cube satellites (cubesats) now. This is going into commercial as well. There was a smallsat conference in Utah in August, with high attendance. Federal agencies involved with smallsats met with the Office of Science and Technology Policy (OSTP) recently. The current orbital debris strategy is adequate but will be re-examined periodically as the number of smallsats increases. NASA provides technical expertise, while the Federal Aviation Administration (FAA) tracks commercial assets on orbit. There is also a partnership with the Air Force.

In Fiscal Year 2017 (FY17), STMD will have some launches and demonstrations. There is a study being conducted on the Centennial Challenges and how to use them more effectively for pulling the technologies back into NASA. He will provide an update at the next meeting.

Regarding the budget, the Agency is committed to supporting SBIR/STTR, but is also committed to developing an approach so that the funding does not all come from STMD. This is relieving the impact on STMD's budget. There will be an analysis of SBIR effectiveness, and the Directorate recently revised the solicitation to eliminate confusion. A virtual presolicitation conference helped applicants walk through the solicitation so that the proposals would more likely be responsive. Dr. Mary Ellen Weber suggested that there should be a strategy to continue the Agency-wide commitment to sharing SBIR/STTR costs.

Mr. Jurczyk said that a new university initiative, the Space Technology Research Institute, pursues specific research areas. The recent solicitation focused on biomanufacturing, and composite materials computational capabilities. STMD hopes to make a selection in late January or early February. These are 5-year awards of $15 million total, and the goal is to solicit them every 2 years.

Dr. Ballhaus asked what STMD would like TI&E to take to the NAC. He had thought of the SBIR budget and presolicitation effort, as well as a chart with milestones for the upcoming demonstrations. He also liked the incentives on the SMD missions. Mr. Jurczyk suggested adding smallsat missions. He noted that STMD still carries the SBIR budget request. For the upcoming change in administration, STMD and other NASA units have a wealth of preparatory materials, including "interest papers" that highlight areas such as technology.

Update on In-Space Manufacturing and Assembly
Ms. Trudy Kortes, TDM Program Executive, provided an update on In-Space Robotic Manufacturing and Assembly (IRMA). This is one of the Tipping Point solicitations, and it has been complicated in the areas of data rights and intellectual property. NASA shares data rights, while companies prefer them to be exclusive, so this had to be negotiated to allow the companies to use their proprietary elements and be competitive.

IRMA is under the TDM program, which seeks to mature technologies to TRLs 4 through 6. This means there is a high likelihood of commercial space applications, and improvement in companies' ability to take the space technology to market. Each contractor uses some NASA expertise and facilities. It all needs to feed the business case. The PTs and the broader community do "gate reviews" to that end. Many companies and federal agencies are interested in these, as shown by their prior investments. Mr. Jurczyk added that STMD has a staff person focused on commercial applications. If there is a need to bring in additional entrepreneurial expertise, they will do so.

TDM awarded three contracts that will demonstrate robotic manipulation of structures and remote manufacture of structural trusses. The kickoff meetings have taken place, and all three contracts will end in a ground demonstration or thermal vacuum test at the component or subsystem level. There is some risk to the companies, and while budget uncertainty is always a concern, STMD is very careful to ensure that it can fund its solicitations under worst-case scenarios.

Ms. Kortes described the Archinaut demonstration from Made in Space, Inc., which seeks to advance in-space manufacturing and assembly technologies for infusion into exploration missions. The project will build a structural segment in a thermal vacuum environment over the course of 2 years in order to demonstrate additive manufacturing and structure assembly. The technology goal is to be able to manufacture and assemble a communications satellite in space.

The next contract is for the Commercial In-Space Robotics (CISR) project from Orbital ATK. This project will involve a 2-year, ground-based risk reduction effort to advance in space manufacturing and assembly technologies for infusion into exploration missions. It will demonstrate robotic reversible joining methods for mechanical and electrical connections, develop a feasible concept to validate space assembly geometries, and demonstrate repeatable module-to-module interfaces for in-space structural assembly. The goal is a robotic assembly, repair, maintenance and refurbishment capability to enable repurposing of spacecraft modules.

The final contract is for the Dragonfly, by Space Systems Loral. This is a 2-year, ground-based risk reduction effort to advance in-space manufacturing and assembly technologies for infusion into exploration missions. The goal is to have platforms from which to manufacture and assemble reflectors. It would enable upgrading of existing spacecraft through use of a robot that would swap out aging reflectors for new ones, thus leading the way to updating payloads or even adding propellant. The team wants to have modules they can reconfigure as needed.

Dr. Weber asked about differences in Manufacturing in Space (MIS) approaches. Beth Fogle, the TDM Mission Manager, added that the concepts are the same, but the truss manufacturing uses different materials. MIS focuses on big structures. Dragonfly wants to build reconfigurable systems. Regarding the return on investment (ROI), it is different for each company. In the case of Dragonfly, the reflectors constitute the immediate success because existing customers want more bandwidth. The longer-term work is a vision. Mr. Jurczyk added that, in some cases, this is a strategic investment. MIS is more entrepreneurial, with a team that is looking at venture capital but also has business plans to move forward. He expects servicing and manufacturing/assembly to come together due to the many similarities.

Ms. Kortes said that TDM has had kickoff meetings with all three project teams, and will provide updates to TI&E as information becomes available. Mr. Gordon Eichhorst said that Goddard Space Flight Center (GSFC) has become involved in additive manufacturing. He wondered if this is still a key area for NASA. Mr. Jurczyk confirmed that it is, with the focus on leveraging additive manufacturing to high-quality components for aerospace applications. HEOMD has invested in additive manufacturing on ISS. It turns out that for plastic printing, there is very little difference between what happens on Earth and on ISS.

Dr. Kathleen Howell asked about development of other 3-D capabilities. Ms. Kortes replied that STMD will try to develop both standards and capabilities. Mr. Jurczyk pointed out that it overlaps satellite servicing, as many sensors and algorithms will work with both.

Mars Architecture Technology Drivers Overview

Mr. William Cirillo, of NASA's Langley Research Center's Space Mission Analysis Branch, explained that this project represents the work of many civil servants. The information is all in the public domain. His presentation would identify human Mars exploration architecture elements that will influence future technology investments, in terms of what drives the needs.

The specific intent of the Evolvable Mars Campaign (EMC) is to identify the option space and the cross-cutting technologies. For that, NASA must also address enabling technologies and sustainable architectures for traveling to and from Mars. These technologies must be robust, with evolvable elements. Some systems should take advantage of SLS and Orion capabilities. At the same time, knowledge gained through current Mars exploration missions will influence the design. Finally, international partnerships are vital to any new mission. EMC is an investigative tool to enable human exploration of Mars in the mid-2030s. EMC requires a broad involvement across NASA.

The key to understanding the architecture options was to develop a set of questions for a team to evaluate and address through multiple trades and analysis. The work is now publicly available. There were also ground rules, assumptions, and constraints reflecting a preliminary scoping of the desired mission to Mars. Mr. Cirillo presented some of the potential trades. The team assumed aggregation in cislunar space and is looking at the use of Mars atmospheric In Situ Resource Utilization (ISRU). The assumption is that there will be six year development schedules for most human-rated elements.

Assuming that a lot of technology groundwork had been done, the team wanted to focus on depth rather than breadth. The vision is for long-duration surface stays with infrastructure at a single site on the Mars surface. The team also assessed precursor cis-lunar and orbital missions. The EMC team analyzed two different in-space transportation options: Solar-Electric Propulsion (SEP) Chemical (SEP-Chem), and Hybrid. Another assumption is that the cargo and crew will be delivered separately. The team did not examine nuclear propulsion, as NASA has not changed its position on that, although it could result in reduced trip time.

The SEP-Chem and Hybrid options both assume a 1,000 to 1,100-day mission in the 2033-39 timeframe. The SEP-Chem option requires long-term cryostorage, which is a key challenge. The Hybrid option requires a refueling capability. A massive amount of energy must be delivered either way, and this requires more analysis and work. Additional launch options could open up the program to allow more partners to make deliveries. NASA's Marshall Space Flight Center (MSFC) is looking at how to advance this. Long-term cryostorage would also open up some options.

For the Mars surface system, the EMC team identified three phases: emplacement, Mars surface proving ground, and utilization. EMC has worked with SMD on surface travel, studying this from both science and exploration perspectives. STMD and HEOMD personnel helped compare propulsion methods. The assumption is that there will be nine SLS launches spread over two and a half to three years, then about three per year. It will be hard to go to Mars at every opportunity, so the EMC team assumes the launches will occur every 52 months.

Regarding cryostorage, the SEP system would involve an eight to nine year period to get near-zero boil-off. The assumption is that there must be technology advances in this area, as there are enabling technologies that are required for Mars. NASA knows what is needed, and can define when the needs come into play in order to drive down the technology risk. HEOMD was about to release a list of needs as well. Mr. Jurczyk observed that STMD will soon know whether it needs additional investment in some areas.

Mr. Cirillo raised the issue of looking at each option in parallel, which could involve some investment issues. For example, if EMC uses the Hybrid approach, the effort will still require cryostorage. He presented the trades and sensitivity analysis, which included the variations in mission planning. He also showed the EMC pathway sensitivity analysis. The chosen path will affect the development schedule and funding. How and when the mission launches will dictate the fundamental architecture. A "short stay" could be two crew on the surface for 7 to 30 days, but the investment would be an issue.

STMD objectives include identification of cross-cutting drivers and solutions; forecasting trends, demands, and opportunities; assessment of the impact of innovative ideas; and informing the challenge and project development. Major Mars human exploration architecture drivers include goals and objectives of the end state; pacing of the pathway; transport of cargo and crew to and from Mars; sources of provision of commodities and resources; and keeping the crew healthy and safe. A number of STMD investments are directly related to these.

As NASA has learned on ISS, crew time is a commodity that is severely limited. The issue becomes one of minimal utilization, which will help to direct investments to alleviate some of the other burdens. Other ISS lessons have to do with the system that keeps the crew alive. However, the ISS mass will not be feasible for a Mars mission, necessitating a different way to keep the crew alive. That will be expensive. Possible solutions address lower levels of repair, commonality of spares, and in-space manufacturing, as well as recycling of spares, improved reliability, and system redundancy.

Dr. Ballhaus noted that some commercial enterprises want to go to Mars and are willing to take big risks. Mr. Cirillo said that these companies might not understand the magnitude of the risk. NASA found that 85 percent of its spares operate better than anticipated, but 15 percent do not. Failures have occurred on ISS, and comparable failures on a Mars mission that is two years out would be harder to address. Dr. Ballhaus observed that the commercial side can bring in a lot of talent and meet many objectives without ever going anywhere. Mr. Eichhorst pointed to the value of ISS in identifying issues.

Chief Technologist Update

Mr. Dennis Andrucyk, NASA's Acting Chief Technologist, noted that the expectation is that the next NASA administrator will select a new Chief Technologist. However, the Deputy Chief Technologist has been appointed. The Office of the Chief Technologist (OCT) is evolving its roles and responsibilities to become more like the Office of the Chief Scientist (OCS), which has no programmatic functions.

He reviewed the Executive Council recommendations from June. Regarding TechPort, the Executive Council was not happy with the current use rates, so OCT is trying to restructure it and communicate the value of TechPort for internal and external collaboration. Dr. Ballhaus wondered if OCT should look at the current situation with innovation at NASA and early career people. It would help to assess the extent to which innovation mechanisms are in place, and if there is need for something else. Mr. Andrucyk explained that there are innovation opportunities in OCT. The proposals are fairly simple. Mr. Jurczyk added that each mission directorate funds a certain number of civil servants at each NASA Center. The centers bring in proposed activities, which are evaluated during an annual planning process. About three-quarters of the funding in Game-Changing Development goes to internal sources. He and the other NASA Associate Administrators have taken on the issue of innovation and are determining areas of under-investment. They hope to fill these gaps. They are also looking at facility capabilities to enable research at lower costs. Dr. Ballhaus pointed out that some work has gone to Europe due to the expenses with NASA.

Mr. Andrucyk said that OCT has funded 13 innovation proposals from a recent solicitation. Most of the proposals dealt with technology, though one was from the procurement area and another from legal. Dr. Ballhaus was concerned about the bureaucratic impediments at NASA. Mr. Jurczyk said that he would be glad to pull together something on this so that STMD can describe the initiatives and TI&E can respond. Mr. Andrucyk said that the innovative initiative is about identifying the barriers, and the team is trying to propose things to address. He would like to come back and show what they have done. Dr. Ballhaus asked about what they think should be done that is not being done. Following a study of the NASA labs 9 years ago, he was appalled at the erosion of their capabilities, the intellectual leadership at centers, the facilities, and the unintended consequences of full-cost accounting. The flexibility was all taken away. Some of that has been restored, but he remains concerned.

Mr. Jurczyk explained that this crosses over into the Agency's operating model. No one on the aeronautics side writes a proposal. All of the in-house work is directed and external work is competed. SMD is very different. So this is a much larger conversation. The better approach is for STMD and OCT to articulate the impediments they see, the solutions they have implemented, and the solutions they would like to implement. Dr. Howell advised that they also encourage getting some feedback from the centers. She knows people at centers who want to write proposals but lack the time to do so. Mr. Green noted that the action item was that OCT will brief TI&E at the next meeting.

Mr. Andrucyk next discussed NASA Technology Executive Council (NTEC) rechartering. NTEC serves as the Agency's senior advisory body on NASA's technology portfolio. It is an internal collaborative group that works on the developing the NASA Technology Investment Plan. The Space Technology Investment Plan (STIP) addresses technology priorities stemming from roadmaps; it was last done in 2012. The 2017 iteration will add a top-down strategic plan. The plan has been drafted but is not ready for release. For the 2017 STIP, NTEC started to determine how to rebalance the investments to 70 percent critical, 20 percent essential, and 10 percent complementary. The new STIP will link to the NASA Strategic plan and the roadmaps, and will include all of the mission directorates and offices. It should be released in the first quarter of 2017.

Office of Chief Engineer Update

Mr. Ralph Roe, NASA's Chief Engineer, discussed activities of the Office of the Chief Engineer (OCE), with a focus on capability leadership. The NASA Technology Fellows or their designees serve as capability leaders for their disciplines. System-level disciplines will be managed at the mission directorate level. Agency priorities will be funded through mission directorates. Each system capability will draw from the teams established under OCE. OCE enforces project management policy across NASA. Some capabilities, like human factors, would cut across mission directorates.

The process is straightforward and takes several months, beginning with an initial capability assessment and involving recommendations from facilities, disciplines, etc., as well as peer review. When a gap is identified in the budget, the new model is no longer stove-piped with centers influencing mission directorates. Instead, technology teams work with members at all of the centers. The Engineering Management Board takes the resulting recommendations forward to Agency strategic implementation planning. This has eliminated some of the internal politics.

Dr. Ballhaus pointed out that the budget had been fragmented and wondered if that has changed. Mr. Roe replied that the NASA Administrator makes the budget decisions. Mr. Jurczyk added that there are discussions for integrated recommendations for the Administrator. The integration is what was missing in the past. Mr. Roe noted that as recently as 2015, it was hard to establish teams. The process elicited 161 recommendations that fall into eight common strategic themes. These themes are Agency-wide topics. Dr. Ballhaus asked if it would make sense for leadership to look at whether NASA can do more to create an environment conducive to innovation. Mr. Roe replied that the previous operating model was the primary issue identified by the technology teams, with the engineering process being second. The cost-accounting model discouraged collaboration. NASA now looks across the entire Agency to see where capabilities lie and whether resources can be moved more easily. Dr. Ballhaus asked Mr. Roe for ideas that TI&E can take forward. Mr. Roe agreed and would get back to the Committee.

He explained that in 2016, 15 teams had done the technology capability assessments, 2 had done the baseline, and 1 had looked only at the scope. Of 123 received, 80 percent fell under the 8 strategic themes, and about half of those could be done by NASA at the engineering level. There will also be peer reviews of the assessments of the capabilities, which Dr. Ballhaus thought was a great idea, as it works well with science. Mr. Roe said that it will help with the collaborations to propel technology development and serve as a good check. The new model should encourage innovation as the teams communicate better, enabling better cross-pollination of ideas.

Agency actions include identification of actions and recommendations to take to the Administrator. OCE actions have the center engineering directors or leads taking ownership of their role in implementing the capability leadership model. The best thing is that this has spurred collaboration among centers and mission directorates, while also recognizing the issues of each group. Dr. Ballhaus noted that the model used at the weapons labs was competition, which had advantages and disadvantages. That was similar when the centers competed. However, this sets up a mechanism for coordination and collaboration. He wondered about when competition would be useful or wasteful. Mr. Roe explained that the model provides data to decide when and where to compete or direct. If a center has a strong capability, it might not make sense for other centers to compete. Now the Agency has data to support competition versus direction, which enables a better decision.

Mr. Jurczyk added that if individuals have good ideas that are not the strength of their centers, NASA wants to encourage them to go to the centers with that strength. No one wants to squash individual creativity. Mr. Roe said they were spending too much money competing with each other. NASA wants its people to be able to collaborate across center boundaries. Dr. Weber asked about the 20 percent that did not fall into the eight theme areas. Mr. Roe said he would present the themes at the next meeting, and noted that the 20 percent did not coalesce into a ninth area.

Small Spacecraft Technology Study Update

Dr. Bhavya Lal, of the Institute for Defense Analyses (IDA) Science and Technology Policy Institute (STPI), provided an interim update on the Small Spacecraft Technology Study. STPI intends to complete the report by the end of the year. The purpose of the study was to identify the focus of STMD's smallsat investments. The approach was to examine smallsat developments and STMD's current and emerging smallsat portfolio, identify smallsat needs at NASA, conduct a gap analysis, and determine the best focus for STMD smallsat investments. The study team looked at work done by industry as well. Data sources included interviews with government, academic, and industry sources; literature reviews; conferences; and a database created for the study. Further plans include use of crowdsourcing and markets to assess trends.

The task addresses the Small Spacecraft Technology Program (SSTP) within STMD. For purposes of the study, smallsats were defined as having a mass of up to about 200 kg, though there were occasional exceptions up to 500 kg. Dr. Asha Balakrishnan, who also worked on the study, explained that SSTP's purpose is to develop and demonstrate new smallsat technologies and capabilities for NASA missions, and to promote small spacecraft for NASA and the larger space community. There have been 63 SSTP awards since the program's inception, with a total investment of about $80 million. Most funding goes to flight demonstrations and university partnerships, as well as some Tipping Point and early career initiatives.

The study team looked at every STMD award, including those for SBIR. They found that most investment goes into three areas: mobility and propulsion, communications, and systems and constellations. Other areas are not funded to the same extent. The study team also looked at the TRL goals of every project, with most being in TRLs 3 through 6. More than half of the STMD smallsat funds to date have gone to universities and industry, with the rest going to NASA centers. Analyses of application abstracts indicate a balance between LEO and deep space.

Dr. Lal said that the team had conducted 40 interviews to date and wanted to do about 20 more. These are not formal surveys, but rather ask open-ended questions about what the users need and want. Mobility/propulsion was strongly seen as important. NASA and university users see a need for higher TRL and believe electrical propulsion is the most likely solution. Industry focus is not homogenous and will require more analysis, but representatives generally think the propulsion issue will require attention soon. Not all of the projects result in a launch. Mr. Jurczyk said that STMD does pathfinders and tries to fly the technologies as they mature. STMD initiates a study to see if they are doable, then flies those that are feasible. Some technologies in the queue might not pan out.

Dr. Lal said that another area of interest was the need for investment in systems and constellations. Interviewees mentioned what they saw, and the study team sorted them. Constellations require advances in many different technology areas, like batteries. Interviews were conducted in parallel with the portfolio analysis, and some of the interviewees said NASA should do more of things the Agency is already doing. STMD needs to communicate better in order to alleviate some of these misperceptions.

Dr. Ben Corbin of IDA said that there are issues regarding rides to the desired orbit. Dr. Lal added that, in the area of communications, all users want higher data rates. Non-NASA users want systems compatible with existing ground stations. The technology needs of NASA users cut across SMD and HEOMD. Both want high Delta V propulsion, image processing, higher data rate communications, and increased reliability. HEOMD seeks rapid flight testing of key technologies, while SMD wants instruments and sensors. There needs to be a roadmap linking SMD and HEOMD. There is also a need to make sure that there are clear science applications for smallsats.

On the industry side, few interviewees identified specific technology breakthroughs in the near-term, as they feel they have what they need for the moment. However, there is a desire for help in advances for both automating the manufacture of satellites and lowering costs. Operators would like to have government as a customer, as well. Bottlenecks include regulations, launches, marketing, and securing customers. It would be helpful to have a curated database of known failures, and there is interest at the universities in working with commercial ground systems and new systems engineering methods. It would be interesting to go back to the companies and ask about the value for the particular sectors; the study team hopes to follow up in this area. Mission life and reliability came up, but there was no consensus. Reliability is not something for which the companies will pay extra.

Among the preliminary findings is that SSTP is one organization in a large smallsat ecosystem. The database sorted through the organizations and found some factors that relate to success. The study team is looking at the number of satellites going up over a period of time. About 3,600 are planned, but some will not launch. The team is also examining leadership at organizations with a space heritage, and doing case studies on the larger companies. Mr. Jurczyk noted that the cost of entry is lower than it once was, which could enable success for some of them. NASA wants to be a purchaser, while also developing technologies where it makes sense. Dr. Lal said that the team is trying to get revenue information. Dr. Corbin explained that a number of companies come out of university projects and want to be bought out. Also, there is a diverse web of connection among these companies, such that pockets can collapse without taking out the whole thing.

Dr. Lal presented another preliminary finding, which was that STMD investments are generally in the right areas. This includes future allocations. Dr. Weber said that TI&E was concerned about whether the companies or STMD should develop resources. Dr. Lal replied that the study team needed to understand what STMD was doing, then look elsewhere. Just because smallsat research funded by STMD is good and important does not mean that SSTP should support it. The team is now studying correction for market and system failures. The team has been to NASA's Ames Research Center to discuss the Smallsat Virtual Institute, and hopes to talk with them again. It is important to understand that investment does not lead to inherent understanding of impact. For that, STMD should do program evaluations. Also, there appears to be a lack of communication of strategy to users and stakeholders. STMD could enhance the awareness of how its small spacecraft technology portfolio relates to specific missions, needs, and goals. Dr. Ballhaus said that the Directorate has made investments, but there is not a sense of the outcomes.

Dr. Jeffrey Sheehy, STMD Chief Engineer, questioned whether it is fair to make these comparisons with a technology development program. For example, optical communication was not aimed at a particular mission. NASA has metrics on the flight demonstrations to provide certain capabilities. Mr. Jurczyk added that STMD does not invest unless it understands that the project will have an impact for science, human exploration, or commercial space. However, there are gaps related to specific missions. Mr. Eichhorst observed that most funding is for flight demonstrations. That could be a source of confusion. The question is whether NASA is furthering the smallsat industry with breakthrough technology. Dr. Lal noted that NASA has, until now, taken an opportunistic approach. Dr. Howell added that NASA can fund risky ideas. Dr. Weber said that some cubesats were not groundbreaking, and some were inadvertently released. Mr. Jurczyk said that NASA does not develop all of the cubesats that it deploys. Some are from universities. Resistance to such smallsat missions has decreased over time, especially with science. SMD is now considering having an Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) ring on every mission. The problem is that the schedules slip, and the orbits might not be synchronized as a result. The primary mission dictates the launch schedule.

Dr. Lal said that the study team is thinking about the role of government in an area with large outside investment. Alignment with the customer requires articulation of strategic intent at the Agency level, clarification of the roles of the centers, and recognition that, in industry, supplier needs differ from those of operators. There is a sense that centers guard their technologies.

Regarding priority areas, Dr. Ballhaus advised looking at the institutional model. Mr. Jurczyk said that he has been trying to work on this. Strategic plans that are actionable take time to implement. Another suggestion was to investigate how to best engage industry in order to move them along while also addressing future mission needs. Dr. Lal said that this is an issue, for there is both duplication in industry and a lot of proprietary work.

Cryogenic Fluid Management Investments Overview

Dr. Sheehy addressed Cryogenic Fluid Management (CFM) with the focus being on propellants. Future NASA missions may require propellant for periods of years. Dr. Sheehy presented a chart on the crosscutting benefits of CFM. The longest storage period of cryogenic propellant has been 9 hours, and sending a crew to Mars will require 9 years of propellant. Nonetheless, there has been progress. One task underway is measuring propellant in microgravity. Transfer lines must be chilled, and there are liquid acquisition lines in the tank. STMD has been working on all of these areas.

Dr. Sheehy told of the Cryogenic Propellant Storage and Transfer (CPST) project history. A new demonstration, evolvable Cryogenics (eCryo), was in formulation but did not have the funding for a planned flight demonstration. However, the technology maturation was robust and the project examined multiple concepts. Dr. Sheehy described four major CPST accomplishments from 2010 to 2014, including boil-off testing with liquid oxygen and liquid hydrogen, and engineering tests. The current eCryo project will do as much validation as possible on the ground through FY19. It incorporates a very large tank, integrated vehicle fluids that utilize boil off instead of just letting it happen, a radiofrequency mass gauge, improved capacity to understand super insulation, and development and validation of analysis tools.

Dr. Sheehy next showed graphics and details of some of the eCryo elements, such as the large tank and the integrated vehicle fluids. The latter will be done in partnership with SLS, and his office will evaluate the feasibility of the concept for SLS upper stages. The final report will be available in the spring. The team is looking at how to meet multiple needs with the radiofrequency mass gauge test, which appears promising. The super insulation project element will test insulation samples for performance data and models for large cryo tanks, expanding NASA's understanding of multilayer insulation. Finally, there will be benchmarking and extension of models.

Zero Boil-Off Tank (ZBOT) experiments will be done on ISS in a series of three small-scale simulant fluid tests, examining the fundamental physics of how these fluids behave in microgravity. NASA will develop the hardware and models both. He thinks the goals can be reached for oxygen and methane. The technology needs significant advancement over where it is now, however.

There have been some good SBIR/STTR projects addressing CFM technologies, and some of these can be leveraged. There are some awards to academia for early stage work, including awards for graduate students. Dr. Sheehy showed a list of key CFM TRL assessments, with the current TRLs and what needs to be done to bring them up to TRL 6. While many of these require flight demonstrations, NASA will do ground work wherever possible. There will also be some integration among certain concepts. In looking at the notional strategy for CFM technology development and demonstration, Dr. Sheehy pointed out that some demonstrations might not be done. However, STMD wants them ready to feed into the integrated flight demonstration planned for around 2020. STMD has invested wisely in this technology and has done some good maturation work in preparation for mission infusion.

Discussion and Recommendations
Dr. Ballhaus began the review of items for feedback to NASA:

1. Acknowledge what NASA Administrator Charles Bolden has done across the Agency regarding technology development, including STMD.
2. NASA is looking at capabilities, which is an important effort, and found a need for commonality of engineering tools
3. STMD is getting more out of SBIR, and held the SBIR solicitation conference.
4. The small spacecraft study.
5. Big demonstrations coming up.
6. Continuation of incentives to include technology demonstrations in SMD missions.
7. Efforts to understand the technology needs of the proving ground missions.
8. Public/private partnerships.
9. The massive number of spares required for EMC are essentially duplication.
10. Homework assignments to NASA on how to incentivize innovation and remove barriers.

The discussion moved to editing the charts Dr. Ballhaus presented earlier, which he planned to present to the NAC. On the charts, TI&E acknowledged the technology progress that has taken place under NASA since 2010. This includes the establishment of OCT in 2010 and STMD in 2013, the rebuilding of the cross-cutting technology program, and the focused technology development in HEOMD and SMD. NASA management has done an excellent job of formulating and executing the technology program. Dr. Ballhaus wanted to keep the TI&E concerns chart. Regarding the proving ground missions, it is not yet possible to assess risk reduction matrices because there is no plan, but the proving ground missions can be assessed once they have been formulated.

It was noted that the shared funding of SBIR/STTR among the mission directorates has not been institutionalized and therefore the next administration could revert back to having STMD take the entire funding burden. Mr. Jurczyk said that this is still being worked on by NASA management. The Committee members remained concerned.

A new chart addressed technology needs to support proving ground missions for human exploration of the solar system. The mission definitions are necessary for assessment of the investment and risk reduction work required to support those missions. It was also noted that in-space robotic manufacturing and assembly provide a good example of a public/private partnership. The chart then listed some upcoming projects and milestones, such as the SEP Preliminary Design Review (PDR), the laser communications Key Decision Point (KDP) C, and others. Another chart advised continuation and enhancement of incentives in technology demonstrations in SMD missions, such as the Discovery program. The IDA study will determine the appropriate focus for STMD's smallsat investments. The final report will be provided in early 2017.

Discussion returned to SBIR/STTR, with a focus on maximizing the return to NASA and providing better support to small business by helping to broaden participation in the program. Centralizing the program in STMD has led to more effective management. STMD held a solicitation formulation workshop with the centers and mission directorates to develop more integrated solicitation topics for proposers. In addition, STMD held a presolicitation conference with prospective small business bidders to help them understand NASA's requirements. The Committee members noted former STMD AA Robert Lightfoot's initiative to assess capabilities and formulate an integrated plan.

Regarding Mars exploration, there is the issue that 85 percent of the spare parts are never used but must be taken. Dr. Ballhaus suggested using it as an example, as there will be the need to take an almost-complete additional habitat along. Dr. Weber did not find this striking. Mr. Jurczyk was more concerned with EDL requirements. Dr. Cirillo agreed to put together some material for Dr. Ballhaus to take to the NAC.

In the review of the charts, TI&E members decided to add a bullet about establishing the space technology research institutes. Dr. Ballhaus planned to present some items requiring additional investments, as well as the proving ground missions and the question about spare parts. From Mr. Roe's presentation, there were major concerns about generating and encouraging innovation within the Agency, especially regarding impediments, the lack of investment in foundational engineering sciences, enabling collaboration between centers, and the need for standardized tools. It was agreed to also mention innovation initiatives.

The following are the observations and findings from the TI&E meetings:

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.

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

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

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

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

Adjournment
The meeting was adjourned at 4:45 p.m.

APPENDIX A

Agenda

NAC Technology, Innovation and Engineering Committee Meeting
November 18, 2016
NASA Headquarters
MIC 6A&B

Nov 18, 2016 – FACA Open Meeting

8:00 a.m.	Welcome and Overview of Agenda/Logistics (FACA Session – public meeting) Mike Green, Executive Secretary
8:05 a.m.	Opening Remarks Dr. William Ballhaus, Chair
8:15 a.m.	Space Technology Mission Directorate Update Mr. Stephen Jurczyk, Associate Administrator, Space Technology Mission Directorate (STMD)
9:00 a.m.	Update on In-Space Manufacturing and Assembly Ms. Trudy Kortes, TDM Program Executive, STMD
9:45 a.m.	Break
10:00 a.m.	Mars Architecture Technology Drivers Overview Mr. Kevin Earle and Mr. William Cirillo, NASA Langley Space Mission Analysis Branch
11:00 a.m.	Chief Technologist Update Mr. Dennis Andrucyk, NASA Chief Technologist (Acting)
11:45 a.m.	Lunch Break
12:45 p.m.	Office of Chief Engineer Update Mr. Ralph Roe, NASA Chief Engineer
1:30 p.m.	Small Spacecraft Technology Study Update Dr. Bhavya Lal, IDA Science and Technology Policy Institute
2:30 p.m.	Cryogenic Fluid Management Investments Overview Dr. Jeff Sheehy, STMD Chief Engineer
3:15 p.m.	Break

3:30 p.m. Discussion and Recommendations (FACA Open session)

5:00 p.m. Adjournment

APPENDIX B

Committee Membership

Dr. William Ballhaus, *Chair*
Mr. G. Michael Green, *Executive Secretary*
Mr. Gordon Eichhorst, Aperios Partners, LLC
Dr. Kathleen C. 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
Dr. Mary Ellen Weber, Stellar Strategies, LLC

APPENDIX C

Meeting Attendees

Committee Attendees:
William Ballhaus, Jr., *Chair*
G. Michael Green, *Executive Secretary*
Gordon Eichhorst
Kathleen Howell
Michael Johns
Mary Ellen Weber

NASA Attendees:
Dennis Andrucyk
Laura Brewer
Trina Chyth
William Cirillo
Kevin Earle
Danny Harris
Stephen Jurczyk, *STMD Associate Administrator*
Trudy Kortes
Susan Mann
David W. Miller
Jim Reuter
Ralph Ro
Jeffrey Sheehy
Terry Spagnuolo
Dave Steitz
Douglas Terrior

Other Attendees:
Asha Balakrishnan, STPI
Jonny Behrens, STPI
Ben Corbin, STPI
Ellen Green, STPI
Ben Kallen, Lewis-Burke Assoc.
Bhavya Lal, STPI
Alyssa Picard, STPI
Amy Reis, Ingenicomm
Elizabeth Sheley, Ingenicomm

APPENDIX D

Presentations

1) In-Space Robotic Manufacturing and Assembly (IRMA) Update for NAC TI&E Committee [Kortes]
2) Mars Architecture Technology Drivers Overview [Cirillo, Earle]
3) Office of the Chief Technologist Update [Sheehy]
4) Office of the Chief Engineer Update [Roe]
5) Focus for STMD's Small Satellite Technology Investments – Interim Update [Lal, et al]
6) Cryogenic Fluid Management Investments Overview [Sheehy]