National Aeronautics and Space Administration

Technology, Innovation, & Engineering Committee of the NASA Advisory Council

NASA Headquarters
Washington, DC
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Meeting Minutes

G. Michael Green, Executive Secretary

William F. Ballhaus, Jr., Chair

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Meeting Report prepared by
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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. A mandatory annual ethics briefing was to take place during lunch.

Opening Remarks
Dr. William Ballhaus, TI&E Chair, began the meeting with a quick review of the previous meeting's observations, findings, and recommendations to the NAC. TI&E members had found that they could not assess the technology investment matrix with the materials they had, and sought both a mission definition and a plan incorporating the technology risk burn down and other information. To effectively work to correct this situation, in the absence of a defined Mars mission plan, the TI&E wanted to develop the technology pull from the proving ground missions and address key technology gaps. Dr. Ballhaus believed that the NAC wants NASA to select a baseline architecture and begin planning before the transition to the next presidential administration.

Dr. David Miller, NASA Chief Technologist, said that this must be articulated to the next NASA administrator, and Dr. Ballhaus suggested that it should be presented to the presidential transition teams. Dr. Miller added that the Agency knows what is critical for moving to cis-lunar space and the follow-on, but it all has to be phased. In narrowing down architectures, NASA has brought together focus teams, one on In Situ Resource Utilization (ISRU) and another on Entry, Descent, and Landing (EDL), with both internal and external advisors. For the cis-lunar phase, the teams are looking at building the space vehicle and habitation.

Dr. Ballhaus advised also considering what not to do. The concern is that NASA is spending a lot, and yet it is unclear what the Agency is getting out of some of the investments. The funding level will not allow NASA to do everything. Dr. Miller replied that there is a tension, in that it is hard to predict the future and therefore set hard dates. Thus, NASA has gone with the incremental approach, which misses the urgency. There should be a date. The International Space Station (ISS) is the least expensive place to test some of these things. However, unlike in the past, it is fully utilized, forcing NASA to make choices about activities there.

Space Technology Mission Directorate FY 2017 Budget and Update
Mr. James Reuter, Deputy Associate Administrator for the Space Technology Mission Directorate (STMD), began the update by noting the Directorate's guiding principles. It is important to have a stakeholder-based investment strategy. The Fiscal Year 2016 (FY16) budget mixes a funding increase that, combined with Congressional direction, constitutes a de facto cut in the discretionary budget. Therefore, STMD managers have talked with their counterparts in the Human Exploration and Operations Mission Directorate (HEOMD) and the Science Mission Directorate (SMD) about priorities. One result is an end to work on the Low Density Supersonic Decelerator (LDSD) program for parachute development. There is a pull for that from the Journey to Mars, but not from the HEOMD side.

In addition, the upper stage of the Space Launch System (SLS) rocket will need to be revisited in terms of composites versus metals. Dr. Mary Ellen Weber pointed out that TI&E had previously heard that the map for investment in EDL technology required investment now, to include parachutes. It was not clear why it was now on the back burner. Mr. Reuter explained that the architecture studies have concluded that all Mars landing scenarios for humans and their cargo require precision, which points toward supersonic propulsion, a technology that also has commercial interest. There will be a demonstration on the Mars 2020 mission. At some point, there will also be a review of the structural interactions of parachutes.

Dr. Ballhaus said that he understood redirecting the parachute funds. However, for the last couple of years, TI&E has been told that composite tanks and EDL would be among the highest priorities. He wondered about the shift. Mr. Reuter said that architecture studies guide the teams. Recent studies on supersonic parachutes led to the conclusion that NASA cannot use what is currently in reach for the necessary precision landings. Meanwhile, SLS and the Office of the Chief Engineer (OCE) recently shifted away from composites in favor of metal.

STMD wants to be guided by mission pull while remaining open to the push. Mr. Reuter showed the enabling future exploration missions, which serve as guidelines. STMD is a small mission directorate and therefore seeks opportunities to incorporate its technologies, which it takes to Technology Readiness Level (TRL) 6. For example, the solar array is going to the commercial sector already, and NASA is not investing further. Hall thrusters will go into the Asteroid Redirect Mission (ARM). The Agency is conducting reference missions for cargo delivery. The Deep Space Atomic Clock (DSAC) will be delivered to launch in 2017, and green propellant is ready to go. There is also a commercial infusion path for laser communication, which will be launched as a demonstration in 2019. In addition, there are five small missions with hardware ready to launch.

Mr. David Neyland said that small spacecraft are a commodity. He was unsure why NASA is supporting these missions under the circumstances, especially with cuts in important areas like EDL. Mr. Stephen Jurczyk, STMD Associate Administrator, said that the focus is on enabling meaningful science missions with cubesats and smallsats. These satellites must be more capable and have more sophisticated instrumentation than what is available in the commercial sector. This effort allows NASA to leverage what is done elsewhere while enabling the Agency's unique needs. Mr. Neyland asked if there has been an independent review of NASA's contribution to smallsats in order to verify that the Agency should invest in this technology rather than buy it. Mr. Jurczyk replied that SMD has charged each of its divisions to study what can be done by smallsats, in order to identify the gaps that need to be filled. That should allow STMD to evaluate what it can buy or leverage, and adjust the investments accordingly.

Mr. J. M. Oschmann pointed out that not all smallsat efforts focus on cubesats. Some elevate technologies and payloads for science, and some of these are being bought. The sensors are what NASA must develop. Dr. Ballhaus said that a number of sources are working on smallsats, but the sensor piece is not a commodity. Mr. Neyland noted that the advancement of the commercial sector for sensing is moving faster than anticipated. Mr. Jurczyk explained that there is a difference between sensing for commerce and for science. The calibration for science is much more refined and precise. The commercial efforts are not close to Landsat levels, for example, and instead focus more on cost and the market needs. Mr. Neyland was not convinced that NASA was in fact pushing the boundaries, and reiterated his suggestion that an independent team look at the extent to which the Agency is using its unique capabilities. Mr. Jurczyk said that some of this has been in the pipeline for years, and much of it does leverage what the commercial sector is doing. These are not all in-house NASA activities, as they involve partnering with business, academia, etc. However, it is a good time to step back and look at where NASA should focus.

Returning to the presentation, Mr. Jurczyk explained that there are two models for public/private partnerships. One is the Tipping Point (TP) demonstration, in which a demonstration or validation would result in rapid adoption and utilization. The second is the Announcement of Collaboration Opportunity (ACO), for those that could directly benefit from NASA's unique experience, expertise, and facilities. Both had solicitations released in May 2015, resulting in 9 TP and 13 ACO projects selected in late 2015. New solicitations will be issued later in 2016 and in 2017. Some companies that did not even propose ended up collaborating with the NASA centers, which was a nice benefit.

Among key STMD activities are two significant new ones: Restore-L and Deep Space Optical Communications (DSOC). The Restore-L program involves refueling satellites in Low-Earth Orbit (LEO); NASA was directed by Congress to move this from HEOMD to STMD and work toward a 2019 deadline. DSOC will be flown on a Discovery mission as a technology demonstration.

Mr. Jurczyk could not discuss the FY16 budget because it was still being negotiated between the House and the Senate. However, he did say that it leaves STMD in relatively good shape and with some features, such as Restore-L, that are definite. Restore-L will require additional funding to meet its 2019 deadline, and that will be presented to Congress. At this point, STMD must identify the requirements. A leadership challenge is to not sacrifice the lower TRL work in the face of budget issues. The FY17 President's Budget Request (PBR) includes a substantial increase for Technology Demonstration Missions (TDMs). The Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) program budgets increase by statute. Allocations for Game Changing Development (GCD) TP technologies and nuclear thermal propulsion technology development increase as well, along with early-stage portfolio growth for virtual institutes and foundation engineering science. Wind tunnels fall under aeroscience, which receives additional funds.

The Green Propellant Infusion Mission (GPIM) is a joint NASA-industry effort that will provide greater propellant efficiency. DSAC has presented some challenges but seems to be through the worst of them. The current Restore-L target will be refueling of Landsat-7. Once the demonstration is complete, this technology will be transferred to industry and help NASA move forward with making spacecraft serviceable. There are five GCD focus areas right now, and Mr. Jurczyk would like to see a broader portfolio on propulsion. An EDL Pathfinder study will explore at least four architectures to land four or more metric tons on the Mars surface.

Dr. Ballhaus asked if it makes sense to fund some things internally in order to maintain the capability and help NASA be a "smart buyer." Mr. Jurczyk answered that STMD needs to be conscious of that and maintain a level of hands-on experience. It should be a conscious choice balanced with industry activities. Commercial cargo is an example of NASA's smart buyer approach. It is a challenge, and moderation is the key.

Mr. Jurczyk reviewed GCD highlights, including a heatshield; a system for locating items on ISS; a heat exchanger; and a photon-counting camera. Dr. Ballhaus observed that the impact is not obvious if some of these programs are cut. In addition, the directed spending on Restore-L results in a $20 million de facto budget cut. Mr. Jurczyk explained that STMD effectively terminated two projects. The LDSD technology will no longer be available to SMD for a Mars sample return mission, and leaves unanswered questions about EDL. The second terminated project is for composites to be used in the upper stage of launch vehicles, which limits SLS and Orion. The Directorate continues funding the civil servants involved in those projects. Some of the longer term projects were validated with HEOMD and SMD as being lower priority.

Dr. Ballhaus said that in order to present this to the NAC, he would need a good impact statement, a list of the five most important accomplishments, the five most important anticipated accomplishments, and the answer to "so what" questions for each of them. Mr. Jurczyk agreed to supply the information. He added that STMD is trying to lower the complexity and costs of nuclear thermal propulsion; this is in the early stage, and the Directorate is trying to maintain the investment in portfolio. He presented some technologies in process for small spacecraft, and gave key milestones for GPIM, DSAC, and solar electric propulsion.

FY 2016-17 Technology Plans for HEOMD and SMD/Discussion

HEOMD
Dr. Chris Moore, Advanced Exploration Systems (AES) Program Executive, began his presentation by showing the key capabilities stoplight chart from the Journey to Mars Design Reference Mission (DRM). AES is responsible for six domains, five of which are technology development activities, with the sixth being the Evolvable Mars Campaign (EMC). The Program expects to achieve about 80 percent of its 65 milestones for FY16.

Dr. Moore began his look at specific domains with the Crew Mobility Systems area. NASA has not introduced a new space suit since 1981. The updated versions will facilitate hands-on surface exploration and in-space operations. There were some budget cuts to the program to develop a walking space suit for surface exploration, so AES will instead concentrate on the Portable Life Support System (PLSS). The Habitation Systems Domain has initiated a series of six fire safety demonstrations, the first of which launched on March 22. The total cost of this effort is about $1 million. The Bigelow Expandable Activity Module (BEAM) will demonstrate a commercial inflatable module on ISS, scheduled to launch on April 8. Once the structural and radiation environments are characterized, the ISS crew will have access to the module. The cost was about $17 million, plus some additional NASA support of around $5-6 million.

Congress has directed AES to build a prototype habitat. The Program selected four Phase 1 studies in 2015, to be completed in June of 2016, at which point AES will have another solicitation for additional partners and move into a Phase 2 study with some in-house testing. There are also plans to demonstrate environmental and life support technologies on ISS, five of which are in process. The current CO_2 processor on the ISS breaks down much too often, which NASA wants to address. Another focus is on radiation sensors to characterize the radiation environments of potential destinations for human exploration, and to update and validate radiation transport models with flight data. One issue across all of this is logistics and minimizing mass.

AES is supporting Orion on the Ascent/Abort 2 (AA-2) flight test, which should launch in late 2019. The Program is also looking at Advanced Electric Propulsion (AEP). These are public/private partnerships with half of the funding from the commercial side. In the area of modular power systems, AES is studying a number of options, including fuel cells. In addition, the fueling of a launch vehicle is very labor-intensive, which is the impetus behind an automated propellant loading project. Software for in-space planning, procedures, etc., should help crews become less dependent on ground-based mission control.

Another area is avionics, software, and communications, where AES is at work on common avionics components, Disruption Tolerant Networking (DTN), and Ka-Band Objects Observation and Monitoring (KaBOOM), mainly funded by the Department of Defense (DOD) but with NASA doing much of the work. The in-space manufacturing area has seen the first demonstration of a 3-D printer on the ISS, which is moving into the commercial area. Synthetic biology applications are also being studied. In the robotic precursor arena, AES is working with SMD on Mars 2020 payloads, including secondary payloads. The Agency is trying to use smaller spacecraft to demonstrate these, as conventional missions would cost more. AES is also trying to establish a new service to deliver payloads to the moon, similar to the efforts to deliver to the ISS. Much of this is commercially driven. The Program is still formulating the resource prospector mission for an ISRU demonstration, and collaborating with Taiwan to develop a lunar lander.

FY17 plans are still largely in formulation. AES will continue to develop prototype cis-lunar habitats, as well as work on ISRU technologies. There will be external partners on some of these. In identifying cross-cutting needs, the program found that the gaps are greatest in Space Communication and Navigation (SCAN), and in human health, life support, and habitation.

AES has 460 civil servants, plus contractors operating in four different areas. Many of the civil servants once worked on the Space Shuttle. In terms of using on-site contractors or building expertise in the big companies, the Program tries to transfer knowledge and technology to the companies building the systems. The AES budget for FY16 is $182 million, with an expectation of something similar in FY17 and more flexibility in FY18. Dr. Miller said that he has been looking at the use of ISS and has found that autonomous opportunities are helping with the crew scheduling. He worries that if NASA treats these as experiments but does not ingrain success into the ISS culture, it will be a missed opportunity.

SMD

Mr. Michael Seablom, SMD Chief Technologist, explained that SMD is guided by each division's Decadal Survey (DS). The Directorate has more than 200 technology development programs. An example is the Heliophysics Division's (HPD's) Chromospheric Lyman-Alpha Spectropolarimeter (CLASP) instrument to measure the magnetic field of the sun. HPD and the Astrophysics Division (APD) do a great deal of technology validation. The Earth Science Division (ESD) has made some investments in smallsats, as well as studying lidar winds. A recent concept for the latter is the Global Wind Observing Sounder (GWOS). ESD has also had a breakthrough in measuring rainfall through a constellation of cubesats, despite having been told that this would not be possible. Through APD, NASA is contributing a laser system to the European Space Agency (ESA) Laser Interferometer Space Antenna (eLISA) mission, which will explore the use of gravitational waves in studying the merger of black holes. The Planetary Science Division (PSD) had smallsat breakthroughs in the Small Innovative Missions for Planetary Exploration (SIMPLEx) program.

Technology development accounts for about 3 percent of the overall SMD budget, which is leveraged by partnerships with STMD on many projects. Mr. Jurczyk noted that there is frequent discussion to ensure that the work between the two mission directorates is complementary. Dr. Ballhaus observed an increasing use of smallsats and cubesats in place of larger missions, which Mr. Seablom confirmed. Recently, there has been some overlap and duplication in these investments among the centers, which SMD is beginning to address. This is not yet the case with 3-D printing, another area of expansion. Dr. Miller added that constellations are enabling more distributed architectures.

Mr. Neyland expressed concern about space debris and clean-up issues resulting from the proliferation of smallsats. Dr. Miller explained that a related issue is custody of the satellites and their debris. HEOMD is working on a transponder and obtaining a signature of the satellites. There are rules of engagement, as well as deorbit technology. Mr. Jurczyk added that the U.S. government needs to relook at its policy on this, but no one wants to be "the space garbage agency." There are international issues as well. NASA will develop but not implement the removal technology. Remediation is a sensitive issue. Mr. Seablom added that most of these satellites are in very low Earth orbit and do not stay up long, though that is likely to change.

Mr. Seablom then reviewed the strategic missions derived from the Decadal Surveys, with notional launch dates. One of the issues in ESD is the increased focus on complementing existing programs, which previously has not been a basis for mission planning. Some of this work is being done in conjunction with the National Oceanic and Atmospheric Administration (NOAA), which is working on a future weather architecture in which the models will work in concert with the observation systems. ESD is examining how to use smallsats to classify instrument and measurement options. At this point, commercial cubesats are not viable for these purposes. Mr. Seablom presented DS science measurement requirements for ESD, noting that alternative approaches provide an equivalent measurement, no clear alternative, or reduced-scope measurement requirements. PSD has a Planetary Science Technology working group to assess identified technology gaps and make recommendations for near-term investments. This group has determined areas of underinvestment and significant gaps.

SMD is updating its strategic technology investment plan, which requires a mix of 70 percent mission-essential technologies, with 20 percent categorized as mission enhancing and 10 percent complementary. The Directorate is looking at agility in planning budgets and how it might shift funds more readily. SMD is trying to determine if technology infusion lessons learned by PSD from the Discovery 14 effort can be expanded to other divisions.

Dr. Ballhaus noted that when TI&E met with the NAC Science Committee, Dr. Matt Mountain observed that SMD takes technology risks on flagship missions while lower level missions penalize such risks. The two committees took that to NASA. Mr. Seablom explained that SMD felt that because of the partnership with Discovery, it was a perception. The part that was missing was Explorers, which have no path for accommodating technology infusion. SMD managers have been discussing this. Mr. Oschmann said that he was not sure about Discovery in that regard. He would address the issue in terms of the Small- to Mid-Explorers (SMEXes), where the community feels the cost caps are too small to allow basic science. Mr. Jurczyk said that in APD, they are also looking at how to get technologies to TRLs for missions that can be included in the next DS. Mr. Oschmann replied that development is part of a flagship mission, but the Technical, Management, Cost, and Other (TMCO) feedback indicates that they want TRL 9 for SMEXes. Mr. Jurczyk said that TRLs should be specific to the missions and technologies. Mr. Seablom added that SMD has, in the past, relied on the suborbital validation of technologies. The Directorate is now determining if it can provide infusion funding for technologies ready to be infused into Explorers.

Chief Technologist Update

Dr. Miller provided an update from the Office of the Chief Technologist (OCT). OCT’s strategic integration area includes four guiding elements: the Roadmap, the Strategic Technology Investment Plan (STIP), the NASA Technology Executive Council (NTEC), and TechPort. The Roadmap was completed in 2015 with input from a range of stakeholders and is the foundation for the STIP’s priorities. TechPort is NASA’s integrated data source, for which OCT is seeking public comment following one-year beta test. Essentially, the Roadmap is what NASA could do, the STIP is what NASA should do, NTEC and the budget tell NASA what the Agency will do, and TechPort describes what is being done. OCT also now has an aeronautics technology area to address, while also dealing with a smaller budget. The Office is considering how to streamline the Roadmap process so that it is no longer a major undertaking every 4 years.

The lifecycle of the Technology Transfer Program moves from identification to protection to licensing and monitoring. Dr. Miller noted the metrics of technology transfer, with areas of growth and areas of concern. Invention by civil servants has declined somewhat, and OCT is trying to bring this up again. Mr. Neyland thought it would be interesting to know if the decrease is related to demographics. Ms. Faith Chandler doubted that it relates to longevity at NASA and suggested that it might indicate opportunities, which could lie more with contractors. Mr. Jurczyk added that NASA is spending less in the areas that could lead to inventions. Mr. Neyland wondered if it might also reflect an emphasis on the Agency having smart buyers rather than inventors. Dr. Ballhaus suggested that it could be the governance model, which used to be that intellectual leadership was at the NASA centers but has now migrated to Headquarters. Dr. Chandler pointed out that NASA has less hardware on the floor these days.

Dr. Miller presented a chart of the technology transfer budget, which is now much less than what it used to be. NASA does not try to make a profit from the licenses, but does try to recover costs. Some of the metrics have gone up nonetheless, especially in the centers. OCT executes critical work for future missions. The Inspector General (IG) report recommended prioritization of core and adjacent technologies identified in the STP, and ensuring use of TechPort as an Agency resource. NASA concurred with these findings and is trying to implement them.

With the new administration coming in 2017, OCT is in a transition year and needs to maintain stability and optimize its activities, while also furthering the growth of space partnerships and the technology forum. OCT hopes to bring three recommendations for interagency strategic collaboration to a May technology summit, building on the successful interagency technology interchange meeting on thermal protection systems. OCT also aims to set the stage for new technology in the move from ISS to cis-lunar space.

Dr. Ballhaus considered it unlikely that there will be much of a budget for exploration while NASA has so many LEO activities. He hears rumblings of extending ISS to 2028, which could delay exploration even further. The sooner NASA shuts down ISS, the sooner the Agency will get on with exploration. There needs to be a cut-off date reflecting urgency. Dr. Miller agreed, but thought that in a constrained budget environment, NASA should consider cis-lunar space in terms of development of a transportation mode and not think of it as the next destination. Mr. Jurczyk added that there is a school of thought that NASA should establish what needs to be done in LEO, then move on. That sounds nice, but it takes funding to shut down a program. Dr. Miller said that it would help if the Agency could use the resources it has more effectively. Multiple factors limit the completion of work on ISS. Mr. Jurczyk said that from the STMD standpoint, the issue is crew time. The Center for the Advancement of Science in Space (CASIS) has half the time, which STMD cannot use. Science gets prioritized in the other half. Funding is the next limitation.

Dr. Weber asked which entity allocates crew time, and wondered if there might be an urgency message that is being lost. Dr. Miller said that his Office is trying to work this through the ISS Utilization Board. This calls for tough choices. Environmental Control and Life Support System (ECLSS) work on ISS is life-critical, for example. The research is held to a different level of scrutiny, however, and they cannot treat it as if the astronaut lives depend on it. Dr. Weber said it would be interesting to see the colored charts with the various needed technologies overlaid with what is being held back due to the ISS bottleneck. She again wondered if the urgency was being communicated sufficiently, and asked if TI&E or the NAC might help.

Mr. Jurczyk said that the ISS Utilization Board needs to ensure that ISS time is optimized for urgent activities, and also address crew time on maintenance. This may require intervention from the NASA Administrator's office. Meanwhile, the human health aspect is well-characterized. ISS reliability is an issue that takes time

Dr. Ballhaus pointed out that Mr. Jurczyk and Dr. Miller will end up discussing with the next NASA administrator the percentage of the Agency budget that should be devoted to technology, as well as the cross-cutting technology and the push technologies. The other mission directorates will eat up any funds sent to them. Dr. Miller thought that HEOMD and SMD should be focusing on the higher level needs. The lower TRL work should be fenced off into STMD and the aeronautics directorate. A leadership challenge is to not "eat the seed corn" and to maintain a balance between the push and pull activities. This is something that needs to be considered, along with where STMD is relative to where it should be. He also wants to think about the distribution of TRL work. He did not cut any early stage work this year; it is roughly 10 percent of the budget.

Working Lunch - Annual Ethics Briefing

TI&E members had a closed session for a working lunch during which they received their annual ethics briefing.

Technology Demonstration Missions Update

Ms. Trudy Kortes, TDM Program Executive, describes TDM activities. TDM develops technologies between TRLs 5 and 7. Some of the Program's projects were mentioned in the morning session, including GPIM, DSAC, Solar Electric Propulsion (SEP), evolvable cryogenics, and others. The launch for GPIM and DSAC will be a big event, as they will be the first TDM missions to launch. Ms. Kortes reviewed TDM's major accomplishments and explained how technology drives exploration. In the previous six months, the portfolio grew from 7 items to 11 projects of various sizes, some of which will officially enter the portfolio in FY17. Among these are the Mars Oxygen ISRU (MOXIE) project and Terrain Relative Navigation (TRN). The eight STMD thrust areas include TDM contributions, with partnerships in seven of them.

GPIM and DSAC will launch in 2017 on a SpaceX Falcon Heavy launch vehicle, demonstrating infusion into the Aerojet product line. This is expected to be a $50 million industry by 2020, and she would like to see it infused into NASA missions. Mr. Jurczyk noted that the safer handling associated with the new green propellant would cut ground processing costs by half and its thrusters will provide greater impulse. Both the Air Force and a Swedish supplier are interested in this. Ms. Kortes explained that DSAC is at the Jet Propulsion Lab (JPL). It will provide improved navigation accuracy 100 times better than today's state of the art systems. Green propellant is going through a qualification test. This is a small effort for NASA, done as part of a collaboration. Three companies are working on the TP effort to advance space technologies in robotic manufacturing and assembly. The plan is for all three projects to get to a thermal vacuum test. Each company has a somewhat different interest. The long-term goal is to build in space and just send up the raw materials.

MOXIE is new to TDM. It will convert CO2 to oxygen. At this point, the requirements are still being determined, but this is a partnership with SMD and HEOMD. A unit will fly on the Mars 2020 mission. Mr. Jurczyk noted that scale-up and reliability will be challenging, but this technology needs to be proven. The project is also looking at how to convert the frozen water on Mars to oxygen. It might go to TRL 7, but the reliability and scale-up would be less. A larger effort will be needed to move beyond the demonstration level, and this will ultimately require in situ testing. Chemical process models will help identify the number of variables captured. The technology cannot be scaled up on the ground due to budget limitations, but that is something that STMD will have to do eventually. Mars 2020 presents an opportunity, and it is not clear when NASA will return to the Mars surface after that. Ms. Kortes said that there are questions about when to move ISRU into the TDM portfolio, but the thinking is somewhere between 2018 and 2022. As Mr. Jurczyk said, there is not a Mars mission on the books after 2020. One reason to go with an orbiter is that some of the existing orbiters are aging and losing capacity. An orbiter could be used to demonstrate a round-trip mission as well.

STMD and SMD are looking at funding development of TRN, though it is early and therefore the project lacks detail. It will strengthen the landing ellipse and improve precision. It will also be required on all human and robotic missions. The Evolvable Cryogenics (eCryo) project is the only totally ground-based TDM project. It will validate cryogenic fluid management technologies. Mr. Jurczyk described the trade-off involved in on-orbit refueling options. The ideal is near-zero boil-off. This project could move to HEOMD eventually. Communicating about boil-off will be a challenge because it is not easy to describe.

Ms. Kortes said that STMD has been looking at SEP for quite a while, with solar arrays being an example. Recent focus has been on high-power Hall thrusters. STMD expects flight units to be delivered in 2019. SEP also supports the Asteroid Redirect Robotic Mission (ARRM). Mr. Jurczyk added that roll-out solar arrays that do not require folding and hinges are being promoted commercially. He was looking at obtaining the numbers on the maneuverability and the fuel savings. Ms. Kortes said that DSOC has been on books for a while. When deployed, it will offer a data rate 10 times higher than today's standard. The Laser Communications Relay Demonstration (LCRD) mission will be in a geosynchronous orbit, and plans are for a 2019 launch. DSOC is slightly behind in phasing. This is being done in partnership with SMD for a possible launch in 2019-2020.

TDM has had infusion successes into both NASA and industry. This includes some of the GCD and early stage projects.

Dr. Ballhaus said that it would be good to review the impact these technologies have had on relevant systems and missions, which Mr. Jurczyk agreed to do. Dr. Ballhaus pointed out that this kind of information is part of showing how essential the STMD budget is. Mr. Michael Johns advised obtaining the same information on the technologies that were halted.

Restore-L Mission Overview and Discussion

Mr. Ben Reed, Satellite Servicing Capabilities Office Deputy Program Manager at the Goddard Space Flight Center (GSFC), explained that NASA's satellite servicing capabilities are widely cross-cutting. He estimates that about four percent of the thousands of satellites that have been launched have had interactions with other satellites, which allows leveraging of capabilities. Being able to use satellite servicing to advance science and exploration is an important function that will rely on resilient and robust architectures.

The Hubble Space Telescope (HST) is an example of a serviced science satellite. It was in a serviceable orbit by design. Servicing capabilities will enable large missions that are otherwise not feasible, and NASA will not send astronauts to Mars until this function is operable via robotics. After showing how the high-level servicing capabilities line up, Mr. Reed said that he wanted to focus on the Restore-L technology demonstration mission, which is now in pre-formulation. As envisioned, the mission will go to a fully functioning satellite and extend its life. However, the mission focus is not on the satellite. Instead, its purpose is to demonstrate the technology by visiting a real satellite that could use servicing to extend its life. None of the satellites considered were designed to be serviced.

The mission will have three phases, each of which will be fully autonomous: rendezvous; grasp; and refuel and relocate. The technology areas of focus are the relative navigation system; servicing avionics; robot arm and software; tool drive system and tools; and propellant transfer system. Relative navigation will address the challenge of autonomous, real-time relative navigation with both non-cooperative and cooperative objects; the mission will use a non-cooperative satellite. Servicing avionics has become more complex since HST was last visited. The challenge of the robot arm is to have it be dexterous. It will also need to move rapidly. However, this arm will enable a number of additional technologies with multiple benefits. A great deal of effort is going into the tool drive system and tools. The tools will not have motors, which will allow the system to add tools as needed. For the propellant transfer system, the key is to provide fuel to a satellite that was not meant to be fueled in orbit. The demonstration will measure fuel flow, which is not normally done, and will help ensure the subject satellite's operational life.

Mr. Reed showed some near-term Restore-L subsystem milestones. Precursor technology will be tested both on the ground and in orbit. For example, the robotic refueling mission on ISS proved that the steps could be done in the same way as they were on the ground. The Raven mission will launch in summer of 2016, with ISS as the destination. This mission will help develop sensors, algorithms, and tracking. It incorporates an off–the-shelf technology that could be used in future Mars missions. Each action of the mission will be communicated to the public. Other U.S. agencies have the need to refuel satellites, meaning that Restore-L could bring significant benefits, such as global precedence in robotic satellite servicing and a new commercial industry that could contribute to the U.S. economy. The nascent commercial servicing industry will also benefit.

On the first elements of Restore-L and the proposed AARM, the robotic parts will look very similar. The six servicing capabilities are what matter most. The intent is to transfer the capabilities to industry within one year of the launch, which is planned for late 2019. NASA's technology transfer approach should support this.

Discussion and Recommendations

Dr. Ballhaus asked the TI&E members to think about the message they wanted to send through the NAC to the NASA administrator. Mr. Neyland said that he has always appreciated the benefits of satellite servicing, so he was glad to see Restore-L. However, with regard to this project, he questioned the evident lack of a relationship between NASA and the Defense Advanced Research Projects Agency (DARPA), which is doing a parallel mission with the same funding in the same timeframe, using the same hardware, the same software, and the same contractors. The two efforts are completely parallel. Mr. Jurczyk said that the difference is that NASA will service a government-owned satellite in LEO, while DARPA is visiting a satellite in Geosynchronous Earth Orbit (GEO). There will be a meeting among the various players at the White House. NASA's executive management has tried to establish a collaboration with DARPA, but that agency is not amenable to working together. There are factors on both sides that have driven this, but NASA continues to seek an integrated effort. Mr. Neyland wanted TI&E to develop a finding to the effect that it is in the national interest to encourage the collaboration.

(Mr. Oschmann thought he might have a conflict of interest. He therefore recused himself and left the room.)

Mr. Jurczyk continued, noting that there are industry approaches to satellite servicing, and the NASA effort must take care to not disrupt potential commercial markets. He advised TI&E to articulate their concerns and issues. He did caution that STMD is not going into the business of satellite servicing.

Mr. Neyland also wanted TI&E to address the issue of understanding debris generated by small satellites. Mr. Oschmann, who had returned to the room, advised encouraging OCT to find a means of driving the schedule in moving toward Mars. Mr. Jurczyk thought that the proving ground concept was a step in the right direction, and expected that eventually NASA will have a set of flight test objectives for proving ground missions. The timing is an issue, however. The plan will help focus attention and resources, unlike a level-of-effort activity. Regarding use of existing technology in proving ground missions, he thought there were other areas that require efforts to advance technology. For example, there should be a year-long simulated Mars transit in cis-lunar space. The proving ground is necessary before a visit to the Mars surface. Mr. Johns observed the potential contradiction in using the ISS as a potential proving ground at the same time they discuss its end, and wondered if that issue should be raised. Mr. Jurczyk said that the current approach to crew time and priorities is not fully effective.

Dr. Weber asked if there had been any consideration to HEOMD and SMD sharing more of the technology costs. Mr. Jurczyk explained that NASA needs both a dedicated technology program, in addition to having programs in those mission directorates to advance their own technologies. The Senate initially had an FY16 budget mark-up designating one-quarter of the STMD budget for Restore-L. After STMD sent the Senate an analysis of the impact and requested the funds for the program that had previously been in HEOMD, the Senate gave STMD some of those funds. The result was a budget gap of about $40 million, which led to cancellation of two projects in TDM. In the end, the Senate appreciated STMD's communication and did the best they could. STMD still has a solid portfolio.

Mr. Jurczyk said that NASA needs the LDSD for sample return but not human exploration. Regarding CEUS, he did not want to paint Mr. William Gerstenmaier, HEOMD Associate Administrator, into a corner on this or make this to look like his problem. He would soon have more details about the effort.

(Mr. Oschmann again left the room due to a possible conflict of interest.)

Dr. Ballhaus wanted to be careful, especially since TI&E had not yet had a briefing about the project. He also noted that he, too, has some interaction with a DARPA situation, and wondered if he should recuse himself from this discussion. However, Mr. Green thought he would be fine. After further discussion, it was determined that both Dr. Ballhaus and Mr. Oschmann were clear of a conflict-of-interest situation. Mr. Oschmann rejoined the meeting.

Mr. Green said that the NAC would receive more on this topic, and Mr. Reuter cautioned that it would not all be done by the July TI&E meeting. Mr. Jurczyk said that the presentation to the NAC would include flight test objectives. Dr. Ballhaus agreed with Dr. Weber's suggestion that they mention the impending end of ISS availability. Dr. Miller said that there is a list of projects to be done on ISS, but not all have funding, nor are they all equally urgent.

As far as smallsats, Mr. Jurczyk agreed that STMD should take a step back and look at its contribution to smallsats. Mr. Seablom's presentation was largely about smallsats, and the STMD work is infused into SMD missions. Mr. Neyland observed that the commercial side is not thinking about space debris, which NASA could address. Mr. Jurczyk said that it was a matter of U.S. policy issue, and NASA could provide technical assistance. Dr. Miller added that the collecting entity would have to get custody of the debris, work out de-orbit strategies, and address similar issues..

Dr. Weber wondered if they should even raise this issue. She was concerned about getting STMD assigned to spend its resources on this effort. Mr. Johns added that it could turn into an unfunded mandate. Dr. Ballhaus said that this is above STMD, and Mr. Jurczyk added that it goes beyond NASA. It needs to be a governmental and international approach.

The Committee approved the following items as Findings and Recommendations:

Finding 1:

In July 2014, the NAC recommended that the SMD and STMD Associate Administrators review the policy that disincentivizes infusion of new technology into small and medium class science missions. The flagship missions utilize new technologies, but smaller missions have not.

TI&E is pleased to see incentives were added to the last Discovery round for inclusion of new technologies that could benefit future science missions. For example, 4 out of 5 selected Phase A Discovery study teams took advantage of these incentives to include new technologies (i.e. Deep Space Optical Communications).

It would be useful to explore similar technology demonstration incentives for other science program mission areas

Finding 2:

Restore-L mission transferred from HEO to STMD

- STMD should be applauded for embracing Restore-L as a nationally important capability demonstration mission.
- However, there was a price, with a net reduction of $37 million in budget to STMD portfolio. Majority of the reductions from TDM, eliminates:
    - Low Density Supersonic Decelerator (LDSD)
        - Inability to accomplish EDL for Mars Sample Return mission with supersonic parachutes
    - Composite Exploration Upper Stage (CEUS)
        - Indefinitely delays the tools and certification methods to enable large, heavily loaded primary composite structures on launch vehicles

        - Lose the early opportunity to improve SLS performance by reducing dry mass?
- It appears that Restore-L has much in common with the DARPA Phoenix program, with the differentiator being LEO vs GEO demonstration
    - Has NASA collaborated with DARPA to the maximum extent possible?
    - Cumulative government investment ~$800 million using a common set of contractors and hardware

Finding 3:

A set of exploration proving ground missions is currently being defined.

- TI&E looks forward to reviewing the risk reduction matrices and technology investment plans associated with the proving ground missions.
- What portion of these risk reduction technology matrices require use of ISS?
- What is the plan to retire these technology risks by the time the ISS retires in 2024?

Finding 4:

The mission utility of small satellites is increasing rapidly and promulgated across industry, academia and government.

The end-of-life issue associated with the operational deployment of thousands of small satellites creates a continually increasing architectural debris problem. There is a need for mitigating this potential debris problem.

Should NASA play a role in helping the government deal with this problem?

Recommendation to STMD AA:

Recommendation: STMD conduct an independent study of current small satellite technology developments to determine the appropriate focus for NASA's small spacecraft technology investments.
Reasons:

- NASA is at risk for having STMD's small satellite technology investments duplicated in commoditized capabilities. (consequence of no action)
- Given this, what is the appropriate, discriminating role for STMD vis-à-vis all the other organizations that are developing small satellite technology?

Adjournment
The meeting was adjourned at 5:06 p.m.

APPENDIX A

NAC Technology, Innovation, and Engineering Committee Meeting
March 29, 2016
NASA Headquarters
MIC 6A (6H41-A)

March 29, 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
8:10 a.m.	Space Technology Mission Directorate FY 2017 Budget and Update Mr. Stephen Jurczyk, Associate Administrator, STMD
9:15 a.m.	FY 2016-17 Technology Plans for HEO and SMD and Discussion Mr. Chris Moore, Advanced Exploration Systems Program Executive, HEO Mr. Michael Seablom, Chief Technologist, SMD
11:00 a.m.	Break
11:15 a.m.	Chief Technologist Update Dr. David Miller, NASA Chief Technologist
12:15 p.m.	Working Lunch - Annual Ethics Briefing by Rebecca Gilchrist, OGC
1:15 p.m.	Technology Demonstration Missions (TDM) Update Ms. Trudy Kortes, TDM Program Executive
2:00 p.m.	Restore-L Mission Overview and Discussion Mr. Ben Reed, Satellite Servicing Capabilities Office Deputy Program Manager
3:00 p.m.	Break
3:15 p.m.	Discussion and Recommendations
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
Mr. Michael Johns, Southern Research Institute
Dr. Matt Mountain, Space Telescope Science Institute
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*
Michael Johns
David Neyland
Jim Oschmann
Mary Ellen Weber

NASA Attendees:
Gina Anderson
Faith Chandler
Rebecca Gilchrist
Nikolai Joseph
Stephen Jurczyk, *STMD Associate Administrator*
Trudy Kortes
David W. Miller
Chris Moore
Ben Reed
James Reuter
Michael Seablom
David Steitz
Anyah Dembling

Other Attendees:
David Gump, Deep Space Industries
Amy Reis, Zantech
Elizabeth Sheley, Zantech

APPENDIX D

Presentations

1) Space Technology Mission Directorate FY 2017 Budget and Update (Reuter, Jurczyk]
2) Advanced Exploration Systems: FY16 Activities [Moore]
3) SMD Strategic Technology [Seablom]
4) Update on OCT Activities [Miller]
5) TDM Program Update [Kortes]
6) The Restore-L Servicing Mission [Reed]