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Technology, Innovation & Engineering Committee
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Meeting Minutes

G. Michael Green, Executive Secretary	**James Free, 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 agenda. He noted that NASA gave an award to Dr. William Ballhaus, former TI&E Chair, for his years of service to the Committee.

Opening Remarks
Mr. James Free stated that this was his first meeting as TI&E Chair, and he thanked the Agency for the opportunity. Much had occurred at NASA since the previous meeting, and he looked forward to updates in hopes of learning how the Committee might help.

Space Technology Mission Directorate (STMD) Update and FY20 Budget Discussion
Mr. James Reuter, Acting Associate Administrator for NASA's Space Technology Mission Directorate (STMD), explained that much had changed at NASA since March 26, when it was announced that the United States would plan for a human Moon landing by 2024. In order to go forward with this plan, NASA must determine what technology is now available and what must be acquired. Nine Indefinite Delivery, Indefinite Quantity (IDIQ) contracts were already out for small landers, and another call was out for the first mission. NASA was also working on identifying payloads for Commercial Lunar Payload Services (CLPS) landers, and the Science Mission Directorate (SMD) had issued a call for extra payloads.

The basic concept of the Lunar Gateway and landers has not changed much, but the emphasis is now on speed and sustainability. The Gateway is envisioned to be smaller for 2024, and selections are imminent. Solar Electric Propulsion (SEP) is integral to that. The intent is to identify the core minimum elements needed and build from there. The focus is on a faster path to a lunar lander, which is envisioned to include descent, transfer, and ascent modules. NASA is considering proposals to speed development. The lunar south pole is the primary destination under consideration, as it is a promising area for finding resources, but the mission could return to the equator.

The internal roles do not change much. There are long-lead items needed for a sustainable lunar presence. The Human Exploration and Operations Mission Directorate (HEOMD) has adjusted a call for integrated systems and service. While the reference architecture has three phases, a company could propose to combine two phases. There are questions about competition, the number of awards, etc. This effort will call for a substantial budget. Both the architecture and the number of providers are in play. Competition will work well in reaching the ultimate goal. All assets have to be used: SLS and Orion remain key, and there will be a need for heavy-lift launch vehicles. International partnerships are very much in play, but the directive is to have a U.S. landing on the Moon, so there will not be much international architecture.

An effort is underway to identify what is already available and what needs to be developed to get to 2024. Another area of discussion is enhancements, such as CubeSats and ground-penetrating radar. In determining the architecture for human landers, the question has been raised as to whether cryogenic fluid management (CFM) will be necessary for a shorter first mission with fewer people. As HEOMD issues contracts, STMD will be playing into the technology and the role of CFM. There is a strong desire to demonstrate that capability.

It can be hard to switch architectures. Refueling is another consideration. STMD had plans to demonstrate it in 2026, with HEOMD involvement in 2028, so there is a question of how to move that forward now. Similarly, to what extent is precision landing needed? Since there are Light Detection and Ranging (LIDAR) navigation agreements with some providers, NASA is assuming a closed loop system will be available prior to 2028.

Mr. David Neyland said that in 2011, the Office of the Chief Technologist (OCT) sponsored a study on manned geosynchronous services that identified all of the pieces needed. He wondered if anyone had looked at that. Mr. Reuter replied that it is continually updated and reviewed at NASA's Langley Research Center (LARC). He could provide it to the Committee for the next meeting. Mr. Neyland noted that if the technologies were identified in 2011, TI&E should be able to see the progress over 8 years and get an idea of the timeline and cycle needed for maturity. Mr. Free added that CLPS is looking for existing payloads, and the Department of Defense (DOD) had a recent smallsat call. It seems that STMD would be best positioned to identify what is ready to go and what can possibly be left behind on the Moon, like a communications relay. A catalog of what is ready would be helpful.

Mr. Reuter said that figuring out access to lunar ice and how to take advantage of it involves multiple mission directorates. They have looked at possibly doing an impact test involving CubeSats or smallsats. There are also questions about the organizational structure, and whether STMD goes completely toward lunar and drops other things. At present, the Directorate continues funding items with strong stakeholder support. There were already plans for a 2022 SEP mission; this schedule is tight and does not change. A CFM demonstration planned for 2024 might be accelerated. Ideas on surviving and operating in the lunar night are under discussion.

STMD Update

Mr. Reuter moved on to a broader update of STMD activities. The Directorate has two basic investment areas: exploration and commerce. The former emphasizes the exploration of Mars and beyond, while the latter covers investments in the growing space economy. Small Business Innovation Research (SBIR) might have opportunities applicable to the lunar focus, and STMD has found the Small Business Administration (SBA) to be receptive. SBA has granted other agencies exceptions on Phase 2 amounts, so STMD is looking at that possibility. If NASA gets a budget increase for the lead-up to 2024, it would fund a lot more Research and Development (R&D). The question is how to focus SBIR and the Small Business Technology Transfer (STTR) programs on lunar exploration, another topic for discussion with SBA. Those funds could be used more quickly.

Another example is the Low Earth Orbit-based Flight Test demonstration of Inflatable Decelerator (LOFTID) project. There is a growing need to be able to land larger weights and mass. Mr. Reuter described a Space Act Agreement (SAA) with ULA on a larger mass decelerator. This will go onto a National Oceanic and Atmospheric Administration (NOAA)

mission, and will ultimately lead to Mars exploration while also promoting commercial activities. NASA has tried to identify which technologies could serve exploration of both the Moon and Mars, and which are unique to one or the other. Dr. Kathleen Howell asked whether standardization definitions apply across NASA. Mr. Reuter replied that NASA tries to distinguish between technology development and engineering development. The technology focus areas have not changed, and STMD works on lower Technology Readiness Level (TRL) projects. Some items will be of joint interest with HEOMD and SMD.

The investment strategy developed prior to March 26 remains relevant; it funds a broad TRL spectrum. The Lunar Surface Innovation Initiative (LSII) will integrate activities on the lunar surface to include mobility devices. More specifically, rovers are led by SMD, HEOMD looks at human exploration devices, and STMD does the technology development. LSII works across the Agency to ensure that all involved are in sync, consistent, and knowledgeable. The technology demonstration payloads will engage NASA and university personnel across the entire portfolio. These have been extremely positive for those involved. A call is out to link them to the lunar surface and/or Gateway activities. SMD has a budget for payloads on Commercial Lunar Payload Services (CLPS).

The shift in emphasis will affect STMD's emphasis in turn. Examples include lunar In Situ Resource Utilization (ISRU) demonstrations for the processing of water and recovery of oxygen. Mini-robots could help address the shifting emphasis from the location of volcanoes on Mars to the Moon, possibly identifying where to land. STMD will continue supporting technologies that are being readied for flight. Mr. Reuter described an issue with the refabricator project on the International Space Station (ISS), where part of the problem is lack of crew time for trouble-shooting. The problem is currently being analyzed on the ground.

In terms of other investments, early stage technologies account for about 8% of the STMD budget. TI&E had recommended 10%, and the Directorate is growing in that direction. SBIR is not included in this calculation. Mr. Michael Johns asked about the percentage of this funding that goes to universities. Mr. Reuter said that it is half to two thirds. Regarding the early stage technologies that progress to use, STMD does track it and he has infusion examples, but they were not readily at hand. STMD is expanding research through the Flight Opportunities program and the options to increase awards for work that supports exploration needs. In addition to the enhanced Flight Opportunities program, STMD is pursuing small spacecraft technologies and maintaining the SBIR/STTR program, keeping an eye towards Mars.

Next, Mr. Reuter reviewed key accomplishments from 2018 and plans for 2019-20. Demonstrations planned for ISS include Astrobee, three small robots to work aboard the ISS, and a 5-year bionutrients study. The Deep Space Atomic Clock (DSAC) and Green Propellant Infusion Mission payloads will go up in June, along with a number of commercial payloads. The Laser Communications Relay Demonstration has been replanned due to an issue. A Tipping Point and Announcement of Collaboration Opportunity (ACO) are out for another round, and the Restore-L spacecraft bus recently went through Critical Design Review (CDR). A recent demonstration had two CubeSats connect with each other using laser communications. SMD reviewed the Deep Space Optical Communications (DSOC) payload that is to travel to an asteroid on the Psyche mission. A metallic asteroid and DSOC

are a problematic combination, as DSOC uses magnets. STMD has taken on packaging to overcome that, which is a cost element.

Mr. Free asked how the upcoming missions and demonstrations align with the Agency plans for 2024 and 2028. Mr. Reuter said NASA is categorizing everything it has in that regard. An example is whether certain composites under development will be ready for use. STMD is trying to determine that. Two of the Space Technology Research Institutes (STRIs) are going through review now, and two more have been selected to deal with autonomous systems behaviors.

Budget

The Fiscal Year 2018 (FY18) appropriation for STMD was $760 million. This grew to $927 million for FY19, though the operating plan has yet to be approved by Congress. The President's Budget Request (PBR) for FY20 is $1.014 billion. In a review of specific lines, which are not yet available for FY19, Technology Transfer fluctuates, reflecting the lunar surface prize. Technology maturation now has a lunar surface line. Restore-L has high interest, but it is also hard to prioritize. The Laser Communications Relay Demonstration will have cost impacts due to provider issues. The Flight Opportunities line grows in FY20, as do In-Space Robotic Manufacturing and Assembly (IRMA), Nuclear Surface Power (NSP)/Kilopower, and CFM.

The CFM line reflects demonstration work. The direction from the FY19 Congressional report language elevates Nuclear Thermal Power (NTP) to $100 million, reflecting very high interest. STMD has yet to demonstrate the technology and fuel elements, but a major study has been initiated. STMD is also looking at long-term storage of liquid hydrogen. The FY20 budget run-out assumes no funding of NTP, with Restore-L as a technology demonstration. These changes would have a major impact on the portfolio. Mr. Neyland asked if a transition accounted for the SEP tail-off. Mr. Reuter confirmed that that was the case. The plan had STMD getting to a qualified state with a Hall thruster, at which point HEOMD will purchase flight demonstration units. The decline reflects this schedule.

Mr. Reuter listed a sampling of current investments driving technology investment by type, such as Orion and SLS; the Gateway; Mars; and lander and surface operations. He also presented planned exploration firsts through 2024. The priority technologies for flight demonstrations include High Performance Spaceflight Computing (HPSC), precision landing, lunar surface power, CFM, ISRU, and SEP. In the Entry, Descent, and Landing (EDL) area, STMD has made awards for lander technologies. The Safe and Precise Landing Integrated Capabilities Evolution (SPLICE) project is being done in-house and includes HPSC. SMD is also supporting HPSC, and NASA hopes to make it multi-use. This technology was already in the works and will now be used for lunar applications, though probably not in 2024. Other capabilities must be realigned in order to take full advantage of it. STMD also planned a CFM demonstration within a few months.

Next, Mr. Reuter listed the six LSII categories: ISRU, sustainable power, extreme access, extreme environments, surface excavation/construction, and lunar dust mitigation. In the area of On-orbit Servicing, Assembly, and Manufacturing (OSAM), the FabLab is developing an in-space, multi-material fabrication laboratory for space missions. A number of technologies are being developed in Deep Space Communications and Navigation. The advanced materials area pulls in the STRIs, one of which is working to improve

manufacturing of high-strength carbon nanotube technology. There is also an STRI on ultra-strong composites by computational design. LRC is looking at the end use of this work. The Center for the Utilization of Biological Engineering for Space (CUBES) is looking at biomanufacturing in space, including foods and pharmaceuticals. There is potential for application later on, as with CO2-based biomanufacturing.

Restore-L and IRMA: Dragonfly Update

Mr. Ben Reed, Deputy Director of the Satellite Servicing Projects Division, described the history of in-orbit satellite servicing at NASA. Future objectives include robotic learning without humans in the loop, legacy fleet maintenance, and commercial servicing, which raise questions about standards and inter-operability. Among other objectives are cooperative fleet maintenance, in-space assembly of very large telescopes, planetary defense, and orbital debris mitigation.

Mr. Reed described first- and second-generation technology transfer aimed at enabling robust servicing. There are numerous desired applications, with mining being just one example. A range of technology, science, and human exploration activities cut across these various areas. In preparation for its upcoming Decadal Survey (DS), NASA's Astrophysics Division (APD) is studying options for in-space large-telescope assembly. Mr. Reed's division is assisting on the four main APD mission design proposals for the DS, and working on Mars sample return technologies.

Mr. Free asked about the driving requirements that must permeate all of the desired applications, and wondered about priorities. Mr. Reed said that funding only comes with requirements. His division seeks cross-cutting technologies. Autonomous rendezvous is an example. The Restore-L suite could be applied to Orion or the Gateway. The Division is examining whether LIDAR is applicable to lunar rendezvous, and looking at how these activities can help the commercial sector. Funding is mostly through STMD, though other mission directorates contribute as well.

The Raven testbed has been on ISS for a couple of years, with infrared and LIDAR, observing many vehicles during that time. It has been extended for 2 years and will consider guest observers since it has achieved the science objectives. The Robotic External Leak Locator (RELL) is another ISS-based technology, identifying leaks and reducing the need for risky spacewalks. There have been three Robotic Refueling Missions (RRMs), which Mr. Reed described. RRM3, launched in December 2018, had a recent anomaly. Crew members were not at risk, and no payload was harmed. Three tools to address the issue have been installed and will begin operating in the summer.

Restore-L was previously intended to rendezvous an autonomous satellite with no humans in the loop. Recently, NASA has explored the possibility of the mission encompassing Telerobotic Assembly and Manufacturing (TRAM) by appending the SSL Dragonfly payload. The previously scheduled launch date is now under review as a result. Mr. Reed showed graphics of the mated configuration test and payload overview. There will be two arms, one of which will be a spare. The operations are the same, but it is not a given that ground-testing and simulation will be accurate. There is the potential to fly Dragonfly on Restore-L mounted on the side as a six-segment reflector. This would enable a test of in-space assembly. The commercial side wants that, and NASA wants large telescopes, so STMD awarded a Phase 1 study that just concluded. Phase 2 would be an in-space demonstration.

Dragonfly has been through its own CDR. The proposed configuration does not interfere with the Restore-L servicing of Landsat 7. This can probably be done with two separate teams. Mr. Reuter added that STMD wants to implement this demonstration, and this presents a viable option. Funding had been an issue. It is so far along that it will launch regardless of PBRs, and there is flexibility. SSL is interested in this area but is not at the point of investing.

Mr. Reed also described the potential to have MakerSat on Restore-L, which would produce a 20-meter beam. STMD wants to demonstrate on-orbit manufacturing complementary with in-space assembly. Cooperative servicing aids will make satellites more easily serviceable; Mr. Reed described a number of these, ranging from photos to subassemblies and components. The goal is to make the barrier to entry as low as possible in building a cooperative spacecraft. There is a spectrum of serviceability.

NASA is assisting the Consortium for Execution of Rendezvous and Servicing Operations (CONFERS), which includes government and commercial entities. Mr. Free asked about the payoff for designing in serviceability. Mr. Reed said that while he could not give a quantified answer, there is value in transferring NASA technology with NASA requirements to industry. The commercial sector has asked for this and companies make their own business case. That is not his area of expertise. In 2017 and 2018, STMD held three industry days for technology transfer, and there were about 40 companies at each. There have been 42 formal requests for information as well. STMD has issued some licenses and a SAA.

Dr. Howell asked if there were plans to establish a set of standards. Mr. Reed said that NASA does not start working on an interface intending to establish it as a standard. More often, standards result from things that are successful in orbit. Dr. Howell suggested that longer term, perhaps there could be more protocols rather than reliance on ad hoc success. Mr. Reed said that there are technology and interface standards with CONFERS. However, he is not funded to produce standards. The Division's expertise is moving technology from mid-TRL to on-orbit verification. They work with several NASA centers, plus a number of universities and other government agencies on this.

Office of the Chief Technologist Update

Dr. Douglas Terrier, NASA Chief Technologist, said that since the previous TI&E meeting, the role of the Office of the Chief Technologist (OCT) has changed slightly, with more focus on advising the Administrator. OCT also has several assignments that address cross-Agency functions. He tries to ensure that OCT is integrated with the mission directorates and centers. Areas of special emphasis include innovation initiatives, strategic integration, and space and technology (S&T) partnerships. Digital Transformation (DT) coordination is moving into OCT as well. The 2017 NASA technology portfolio allocation was more than $2 billion across the Agency, encompassing science, aeronautics, space technology, and human exploration. OCT coordinates this, with the goal of having a coherent set of activities.

Mr. Neyland wondered about the extent of the technology developments in the four areas. Mr. Green explained that aeronautics does not do as much with STMD. Mr. Neyland pointed out that material science and autonomy are both crossovers warranting attention, and NASA is missing out by not getting to the technology and innovation aspects. Dr. Terrier said that OCT needs to understand that well. The mission directorates differ in their terminology,

which is another issue. Mr. Reuter added that autonomous systems have capability leadership teams that bridge some of the gaps. Dr. Terrier said that OCT is trying to address the linkages in the technology integration framework. The nomenclature is not always the same, and the priorities shift. Over the last year, OCT has identified framework steps, but the strategy for development is where most gaps occur. The strategic plan is a living document.

Mr. Free asked if there are dates associated with the various goals and objectives. Dr. Terrier explained that there are, and each development strategy has stages and exit points. OCT continues working on this in order to make more informed decisions, which he hopes to share at the next TI&E meeting. OCT collects data through TechPort, using it to capture mission directorate reporting and requirements. He would like to see this used in budget formulation. NASA needs to leave room for early stage technology development that is not yet specifically linked to missions.

The innovation framework mirrors the technology process. In 2013, OCT identified barriers to innovation and moved forward from there. The National Academy of Sciences (NAS) brought in experts to describe management of innovation initiatives in other government agencies and in industry. This discussion was organized around a future state discussion that imagined a failure state and discussed how to prevent it, with emphasis on people, partnering, processes, and portfolio management. OCT aggregated the resulting advice into six points, which Dr. Terrier noted. These will be addressed at an upcoming retreat to discuss innovation and create a plan to move forward. OCT is also creating and deploying an innovation portal to coordinate work from the centers, and conducting high-impact innovation experiments to drive change. Mr. Free observed that NASA is criticized for not looking at innovation from suppliers. Dr. Terrier replied that partnering encompasses that. Some innovation comes in through procurement, for example. Innovation is squishy, however, and it can be hard to articulate why something helps.

Dr. Erica Rodgers of OCT explained some of the issues in obtaining varied perspectives and overcoming the issues presented by differing terminology. An example is a discussion on spacecraft development and operations, including in-space assembly. The National Reconnaissance Organization (NRO), Air Force (AF), Defense Advanced Research Projects Agency (DARPA), and Naval Research Lab (NRL) are also involved in in-space assembly. The S&T Partnership Forum began its efforts by working towards a common lexicon. Dr. Terrier said that the process began with identification of common needs. From the initial list of 16 needs, the Forum selected 4 from which to start. Mr. Free asked about conflicting priorities among the agencies, and how the Forum determined which elements within the agencies speak for those agencies. Dr. Rodgers said that the partnership recognized those concerns and spoke with multiple groups within the agencies. Dr. Terrier added that the chief scientists and engineers of the agencies met. There is indeed some tension among the priorities, so work continues on identifying the common needs. Dr. Rodgers explained that within NASA, the key is to include the mission directorates at all times.

The process involves analysis, data collection, strategic discussions, review, and reporting. In Phase 2, the Forum collected and analyzed government data, and the same was done for the commercial sector in Phase 3. Findings include a need for active interagency partnering. The effort established mutual interagency interest in 14 capability areas and 4 capabilities. This evolved into a prioritized set of capabilities. The capability analysis is already being

used at the AF and NASA. Dr. Rodgers showed the need and investment matrix, with priorities based on efficiency, high potential, etc. She also presented potential operational missions going forward into the future. The effort analyzed various platforms in development that would help demonstrate prioritized capability needs.

Recommendations included assessment of data to find strategic, programmatic, and technology priorities. In addition, emphasis was placed on transitioning to ensure that the right teams are included. In regard to implementation of the strategic coordinated approach, SBIR is an example of an avenue. Mr. Free was concerned about the alignment of government and industry. Dr. Rodgers explained that Forum participants have met with industry. The alignment statement is about which sector leads what. Mr. Johns asked how they plan to strengthen partner agency relationships. Dr. Rodgers said that that would be done through continuous dialogue and ongoing meetings to maintain the relationships.

Dr. Bryan Biegel of NASA Ames addressed the Digital Transformation Initiative, which encompasses big data, cloud computing, and more. The final plan includes six prioritized initiatives that address data, collaboration, modeling, process transformation, culture, and AI. Dr. Biegel gave an example of how DT was used in a 2013 incident in which water leaked into an astronaut's helmet during a spacewalk. Post-incident analysis took contractors 2 weeks.

Dr. Biegel reviewed the DT drivers, vision, and goals, using digital convergence as an example. Efficiency, agility, and insight are hallmarks of DT. The six strategic initiatives cover everything the Agency does. Each initiative has an associated working group to engage the corresponding Agency communities. By the end of 2019, they will have a detailed strategy to reach digital maturity; a roadmap; a plan to engage the required capabilities; and an effort to advance early win initiatives. Dr. Biegel closed by listing proposed actions.

Mr. Free observed that to facilitate implementation, "goals and visions" need to be engrained as part of Agency operations, as opposed to being parked in charters and working groups. Dr. Terrier agreed that they do need to figure out where it becomes active rather than theoretical. The effort is still trying to identify the good things people are doing already, as well as the gaps. There is still a need for common strategies. They need to look at the return, as well. It is important that people distinguish between digitizing and taking advantage of digital technologies; this is about the latter.

Nuclear Thermal Propulsion Update

Mr. Sonny Mitchell, Project Manager for NTP, reviewed how NTP engines work. NASA tested 20 NTP reactors in the 1950s-1970s, but the current regulatory environment is quite different, requiring new approaches. The emphasis is now on Low Enriched Uranium (LEU), which has fewer security concerns and more testing options. NTP offers a number of benefits, including flexibility and favorable combinations of the lowest total mission mass and shortest mission durations compared to chemical or solar electric propulsion. It enables significantly shorter trip times than chemical propulsion, reduces each leg of trip time, extends abort capabilities, and reduces the number of heavy lift launches required compared to chemical propulsion.

The project emphasizes the feasibility and affordability of LEU with cost and schedule confidence. Mr. Mitchell reviewed the approach and described the roles and responsibilities of participating organizations. In ground-testing these systems, development challenges include fuels/reactor; integrated engine design; and integrated stage design. The technology maturation plan is specific to the engine the program has in mind and requires getting the fuel and engines to the level of Preliminary Design Review (PDR) for full-scale development. The fuel elements are more challenging than the engines. Developing ground facilities for testing means a concurrent commitment to reach TRL 6 or higher.

Mr. Mitchell confirmed that flight break-up on launch is part of the discussion. The main concern is how to carry the mass. The time and budget for PDR are projected to be 4 years and $300 million to the first half, then another 4 years and $1 billion. That only gets to technology maturation for ground testing. The studies will bear out the time and cost for flight demonstrations. There is much focus on fuel element fabrication and test strategies, which Mr. Mitchell described. This includes packed powder cartridge development. Four cannisters welded together have been delivered to Marshall Space Flight Center (MSFC). The welding has been an issue. He described the hot and cold end testing milestones and the development of the Spark Plasma Sintering (SPS) Cermet fuel element at MSFC. Upcoming work will address a risk reduction test. The needs align with those of DOD to a great degree, but not perfectly.

Dr. Howell sought to confirm that they were at least a decade from TRL 6. Mr. Mitchell said that that is true in the traditional approach. The team has spent the last 2 years developing the approach and defining for cost and schedule. The system feasibility analysis will determine the viability and affordability of an LEU-based NTP engine with solid cost and schedule confidence. The project goal is testing that leads to technology maturation.

Mr. Richard Ballard described the flight demonstration study, which will assess a multi-year plan for an NTP flight demonstration. An internal study at MSFC will evaluate a number of NTP concepts for this. Mr. Reuter noted that the fundamental testing has not been done. The FY19 appropriation includes report language saying that $100 million should be applied to NTP, with $70 million of that going to a flight demonstration. STMD has previously applied some of that to CFM, which is part of NTP flight. They are now looking at what would be involved in actually having a flight demonstration.

Mr. Ballard said that there is a formulation plan study evaluating NTP concepts, inviting industry concepts, assessing users, and looking at additional fuel types. He described the two flight demonstration options being considered: FD1, which targets a 2024 flight hardware delivery, and FD2, which is longer term. The team is also doing customer utilization studies with SMD and DOD, getting the industry perspective, and planning an outbrief to STMD on Mission Concept Review (MCR)-like programs.

Mr. Free asked if this removes anything from the Technology Maturation Plan (TMP). Mr. Ballard said that it would not occur immediately, and FD2 would leverage the TMP. Mr. Reuter added that the idea is to create a testbed in space, but not necessarily the final version. He confirmed that those advocating this approach maintain that once the technology is flown, there is no need for ground testing. There would need to be modifications after the first flight. FD1 would lead to the FY24 flight demonstration, sacrificing performance for schedule in an extremely simplified approach.

Mr. Neyland asked what criteria they would use in deciding between FD1 and FD2 when there is no mission requirement. Mr. Ballard said that there are many indirect benefits to launching FD1, which would require fewer ground facilities. Mr. Mitchell added that in this environment of taking more risks to innovate, they could do a lunar tug. Many of the thoughts are rough. Mr. Neyland again asked what criteria they would use in deciding between FD1 and FD2. The 10-year program seems to have few advantages. Mr. Mitchell explained that they are not the decisionmakers; they provide data. Mr. Reuter added that they would like to look at it in terms of the size of the increments. Mr. Free asked about the missions for FD1 and FD2. Mr. Reuter said that the studies will reveal this. If the only goal is to do a demonstration, it will be FD1. This is of interest to other agencies. If NASA had the funds, they would spend it on retiring risk to help make informed decisions. Mr. Mitchell added that the Department of Energy (DOE) is interested in FD1, which reduces the 10 years of testing he described earlier.

Mr. Ballard reviewed the NTP flight demonstration notional requirements, which will need to be finalized. The flight demonstration design concept will be developed by a collaborative team of engineers from MSFC and DOE. The integrated system design process for FD1 will be driven by the flight date of 2024, while the FD2 process will be driven by user concept studies. Mr. Free noted that both are driven by launch vehicle availability, which is limited to only a few options. Mr. Ballard presented the formulation study schedule. Mr. Neyland asked if anything in the design of the reactor core would prevent it from being used in electric propulsion. He also wanted to know if they were looking at closed loop cycles. Mr. Tyler Scogin and Mr. Mike Houts added that DOE is looking at this, in the tens of kilowatts. Regarding interest on the commercial side, Mr. Mitchell said that when the team met with Blue Origin, they found a great deal of interest.

Office of the Chief Engineer Update

Mr. Joe Pellicciotti, Acting Deputy Chief Engineer, provided an update from the Office of the Chief Engineer (OCE). The purpose of engineering R&A is to advance tools for engineering. This encompasses basic research and engineering methods, with the goal of continuing investments that advance these engineering capabilities. OCE works to build NASA's core engineering capabilities and provides investment in lower and mid-level engineering research, while also enabling more efficient and effective investments.

In 2016, STMD was given an action to work with OCE in developing FY20 investments in engineering R&A activities. Mr. Pellicciotti showed the tentative process by month. Mr. Free asked about how awardee time is allocated, given that they presumably have jobs involving other projects. Mr. Pellicciotti said that NASA assumes that they have management support. Mr. Reuter added that there are similar issues at the centers. Mr. Pellicciotti listed previously identified engineering R&A candidate project topics. Some have been overcome by events, but OCE will examine the list again in order to allocate FY20 funds. He noted that DT is part of a larger exercise that could be included if funds remain. However, OCE has focused on model-based engineering.

Discussion and Recommendations

Mr. Green noted that the next NAC meeting would be at the end of May, giving TI&E plenty of time to craft Mr. Free's briefing. The process was to assemble slides, including a sampling from the presentations, to which Mr. Free could speak easily. That would be followed by any

findings and recommendations; the latter have a specific format. He was not sure the Committee would have any new recommendations this time, so he advised discussing the points TI&E would want to make to the Administrator and the NAC Chair. The draft would be circulated to members via email for their input.

Mr. Neyland said that it felt like NTP was being "slow-rolled." It appeared that STMD has an approach that could meet the language. The CFM work was funded separately, and it came across that STMD did not want to do NTP and therefore swept other things into it. That was not a good story, in his opinion. Mr. Free agreed that the Agency has to decide what it is doing with NTP so they are not always 10 years out from NTP. However, there are a lot of cryogenic technologies that need to be developed to enable it.

Mr. Reuter said that there was validity in the comment. STMD balances its priorities within the budget constraints it is given. The first priority is lunar exploration. Until STMD has demonstrated fuel elements, they do not want to go to a flight demonstration. The situation is that of substantial cost growth and schedule delay. CFM is necessary for NTP and has other uses as well, which is why it is a higher priority. He likes NTP and the concept of the flight demonstration, but he wants to go through the risk demonstration phase. It is a judgment call and a matter of balancing the portfolio.

Mr. Free said that the Agency will need to make a decision about NTP after the FD1/FD2 study is done. Building FD1 will delay building FD2. Mr. Reuter said that NASA is interested in the common fuel forms, and STMD has talked with multiple agencies. Now is the time to have a finding in this area. Mr. Free observed that this fits the focus on the Moon with an eye toward Mars. There needs to be a top-level view of NTP.

Mr. Johns said that he would not comment because of a possible conflict.

Dr. Howell said that she would like a statement on the need for some kind of buy-in on NTP. Dr. Mary Ellen Weber, participating remotely, suggested expressing the concern in terms of a finding, such as "investment in advanced CFM is a necessary component of NTP, and proceeding with FD1 and/or FD2 would delay that." Mr. Green suggested they put it in terms of what STMD has been doing, which is engaging in risk reduction. A consensus seems growing among various stakeholders that they might want to move forward. There is now a multi-agency study at MSFC. The finding could be that when that is in, the Agency and other stakeholders need to agree on a path forward.

Dr. Howell was concerned that it was all open-ended with no clear direction. Mr. Neyland added that the presentation mentioned a tradeoff in thrust but included no numbers. He asked about the specific impulse. Mr. Reuter said that they might be able to reach 700/second. Mr. Neyland said that the concern is that there are paths leading to a more immediate solution, and trade studies are being done now. A commitment needs to be made that will be most beneficial to the constituent communities.

Dr. Howell asked if it was fair to say there may be a path to a broader capability? Mr. Reuter said that the Administrator wants to proceed with NTP. DARPA is interested in NTP, as are others. It has a lot of political support. Mr. Neyland observed that this could be a bell-ringer that heralds what NASA is about. That leads to the question of what holds the most advantage – an early demonstration of limited capabilities, or spending 10 years on an

effort and risk getting it axed multiple times? Mr. Green suggested stating just that. Mr. Reuter advised including the Moon to Mars emphasis. Mr. Free wanted something actionable. He would like to see the results of the feasibility study taken and put into a flight demonstration or flight design.

Mr. Neyland thought they might make an observation this time, get an update at the next meeting, and make a recommendation after that, which Mr. Free liked. Dr. Weber suggested they stated that the Committee is encouraged by the interest in NTP, make it very positive about the study that is happening, and encourage NASA to carefully consider its options going forward. Mr. Free thought it was good to take a positive approach.

In discussing other items, Dr. Howell asked if they wanted to reiterate the goal of having 10 percent of the STMD budget for early stage innovation. She wanted to keep it in the forefront. Mr. Johns advised wording it to state that 10 percent is a target. He asked about repeating the message of NASA keeping an independent space technology organization. Mr. Green said he would pull the finding from the March 2018 NAC presentation, repeated at the December NAC meeting. Mr. Free wanted to include the words "protect and promote" in reference to technology investment and university grants and fellowships. Mr. Johns pointed out that the technology budget could get consumed if it is not kept separate. Dr. Weber asked if they should mention the increased funding and applaud NASA and Congress for continuing to invest in technology.

Dr. Weber said she would also note the investment in technologies that may be useful in the future. If this were a lunar technology division, it would lose those investments to the detriment of NASA. She wanted to make the point about protecting independence. Mr. Free thought they should keep the statement to functions and not get into the organizational structure. Mr. Johns suggested stating that there should be a separate technology focus. Mr. Neyland pointed out that a separate budget line becomes an easy target. Mr. Green showed the March 2018 finding, noting that nothing has been decided and there are new people on the NAC. The Committee agreed to take this forward again and possibly add the word "protect" to it.

Dr. Howell pointed out that the DT piece did not include the views of the academic world or of labs, where AI is taking off. Dr. Terrier agreed. An observation about the need to leverage the work would be very helpful. They need to continue benchmarking. Dr. Howell suggested making it positive, and going beyond the 2024 timeframe.

Mr. Free was concerned about Dragonfly. There were a lot of issues concerning Restore-L and the way the funding has gone, and now they are adding a significant package late in the game. This seems like a large risk. Mr. Reuter agreed that this was valid. He noted that Dragonfly was almost at CDR itself. STMD gave SSL direction from a Tipping Point award, asking them to look at this, but he hesitated to make assumptions. There is also the annual cycle of whether or not to even fund Restore-L, but NASA has already bought the bus for the mission. It was the only way to keep Dragonfly from dying, though it is a risk. Mr. Free asked for an update at the next meeting. Mr. Reuter agreed to do this.

Mr. Free said that the commercialization of satellite servicing and the statement about not doing business cases seemed inconsistent. Mr. Reuter said that there are a few pieces of the demonstration that have high interest. Mr. Green said that when this discussion took 3 or 4

years ago, industry was very insulated and not interested in sharing. That mindset has changed. Mr. Neyland said that the business case question was odd. DARPA spent a lot of time on that, and industry said they did not want to be refueled. Maybe the reason Mr. Reed did not have a business case is because there is not one. Mr. Free pointed out that Northrop Grumman has come up with a business case because they are moving forward with the technology.

Mr. Free asked about OCT expectations for integration and coordination across the Agency. Dr. Terrier said that it is an ambitious charge. The Office needs to look at duplication, among other things. There is also concern about how to have a strong universal means of defining expectations. He will provide more at the next TI&E meeting. By then, there will be more data to enable assessment, and the Office will know more about traceability. It was suggested that the report to the NAC state that TI&E looks forward to more progress and information.

No other points were raised. The next meeting will include many updates. Mr. Green said that it will be the annual all-hands meeting, most likely held away from Washington. Because of the timing of the May NAC meeting, he thought the following meeting would occur in August or early September; they will know after the upcoming NAC meeting. Mr. Green would put together charts and send them out for review to Committee members.

Adjournment

The meeting was adjourned at 4:38 p.m.

Appendix A

Agenda

NAC Technology, Innovation and Engineering Committee Meeting
April 30, 2018
NASA Headquarters, Room 5H41
300 E Street, SW, Washington, DC 20546
Dial-in number: 1-844-467-6272 Pin Code: 102421

April 30 – FACA Public Meeting

8:00 a.m.	Welcome and Overview of Agenda/Logistics Mr. Mike Green, Executive Secretary
8:05 a.m.	Opening Remarks Mr. Jim Free, Chair
8:15 a.m.	Space Technology Mission Directorate (STMD) Update and FY20 Budget Discussion Mr. James Reuter, Associate Administrator (Acting), STMD
9:45 a.m.	Break
10:00 a.m.	Restore-L and IRMA: Dragonfly update Mr. Ben Reed, Deputy Director, Satellite Servicing Projects Division
11:00 a.m.	Office of the Chief Technologist Update Dr. Douglas Terrier, NASA Chief Technologist
12:00 p.m.	Annual Ethics Training Ms. Kathleen Teale, Attorney, NASA Office of the General Counsel
1:00 p.m.	Lunch
2:00 p.m.	Nuclear Thermal Propulsion Update Mr. Sonny Mitchell, Project Manager, Nuclear Thermal Propulsion Mr. Les Johnson, Formulation Manager, Nuclear Thermal Propulsion
3:00 p.m.	Office of the Chief Engineer Update Mr. Joe Pellicciotti, NASA Acting Deputy Chief Engineer
3:30 p.m.	Discussion and Recommendations
5:00 p.m.	Adjournment

The WebEx link is https://nasaenterprise.webex.com, the meeting number is 902 250 755, and the password is "n@cTIE0419" (case sensitive).

APPENDIX B

Committee Membership

Mr. James Free, *Chair*
Mr. G. Michael Green, *Executive Secretary*
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 (retired)
Dr. Mary Ellen Weber, Stellar Strategies, LLC

APPENDIX C

Meeting Attendees

Committee Attendees:
James Free, *Chair*
G. Michael Green, *Executive Secretary*
Kathleen C. Howell
Michael Johns
David Neyland
Mary Ellen Weber, *via WebEx*

NASA Attendees:
Rick Ballard
Anyah Dembling
Mike Houts
Susan Minor
Sonny Mitchell
Joe Pellicciotti
Ben Reed
James Reuter, *STMD Acting Associate Administrator*
Erica Rodgers
Tyler Scogin
Kathleen Teale
Douglas Terrier

Other Attendees:
Linda Karanian, Aerojet Rocketdyne
Amy Reis, Electrosoft
Elizabeth Sheley, Electrosoft

WebEx:
Stephen Clark
Jeff Foust
B. Harvey
Dave Huntsman
Frank Ledbetter
Susan Minor
Kurt Sacksteder
Nicholas Siegler
Bill Stiers
David Steitz
Mary Ellen Weber

APPENDIX D

Presentations

1) FY2020 Exploration Technology Budget Update [Reuter]
2) Satellite Servicing, Assembly, and Manufacturing Update: Restore-L and IRMA [Reed]
3) Office of the Chief Technologist Update [Terrier]
4) Nuclear Thermal Propulsion Update [Mitchell]
5) Office of the Chief Engineer Update [Pellicciotti]