National Aeronautics and Space Administration

Technology, Innovation & Engineering Committee
of the
NASA Advisory Council

NASA Kennedy Space Center
Merritt Island, Florida
October 29, 2019

Meeting Minutes

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G. Michael Green, Executive Secretary **James Free, Chair**

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NAC Technology, Innovation and Engineering Committee Meeting

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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 thanked Mr. Robert Cabana, Kennedy Space Center (KSC) Director, for the previous day's tour.

Opening Remarks

Mr. James Free, TI&E Chair, greeted Committee members and NASA employees. He then introduced Mr. Cabana.

Welcome to Kennedy Space Center

Mr. Cabana explained that while KSC is an operations center, it has also done some good research and testing (R&T). He presented a movie that highlighted KSC accomplishments and activities. A priority is commercial crew. KSC has more than 200 agreements with over 90 entities from the commercial and academic sides. The Space Shuttle landing facility was turned over to Space Florida, though NASA has free use of it. Companies and organizations like Boeing, Lockheed Martin, and the U.S. Air Force do some work at the Center, and Exploration Park is a related facility outside KSC. Mr. Cabana reviewed some of the programs and contracts, noting demonstration tests that have occurred in 2019 and that will be done before the end of the year. He expects 2020 to be busy, with activities such as the launch of the Mars 2020 rover.

Mr. Cabana noted the need to shuffle some testing due to the SpaceX setback earlier in the year. Boeing hot fire and parachute tests were conducted in May. The Artemis program will return NASA to the Moon, which will serve as a proving ground for Mars exploration. The original 2028 plan has been accelerated to 2024, and Congress has before it a budget increase to make this happen. The Gateway is essential for the 2024 landing. The first Artemis flight will be an uncrewed Orion and SLS trip around the Moon, followed by a crewed mission that will not land. The third Artemis flight will be a human landing. Technology development for living away from Earth will take place at the Moon, as it is close to Earth in case there are issues. NASA is working on lunar dust mitigation, habitats, cryofluid management (CFM), in-situ resource utilization (ISRU), and more.

Mr. Cabana also explained some of the work being done in the area of Exploration Ground Systems and launch vehicles. In the vehicle assembly building, teams are working on the enhanced upper stage. The mobile launcher is complete and going through verification and validation, which have uncovered some issues. However, this is the rationale for testing. KSC is also building the largest liquid hydrogen sphere in the world, and works in the area of landing and recovery. KSC now employs NASA's first female launch director. The Center is running launch simulations for Orion and should have the software complete and tested by next spring. Among the exploration R&T programs is plant research, which has shown that there are psychological benefits to growing plants. ISRU is another research area. A roadmap of launches for the next five years includes 65 NASA launches. Increasingly, the Agency is partnering with industry and international entities. While the first phase of the Gateway will be NASA alone, international partners will participate in Phase 2. KSC is a great place to be right now.

Space Technology Mission Directorate (STMD) Update and Discussion

Mr. James Reuter, Associate Administrator (AA) for STMD, discussed the path to the lunar surface. Now is a critical time for technology development enabling a sustainable lunar presence. STMD has items on the critical path for flight-qualifying thrusters and has made other contributions, such as solar arrays. For the human landing, there are arrangements with suppliers and lunar payload services with the Science Mission Directorate (SMD). Human landing system proposals were due that Friday, and CFM will likely be in the initial proposal.

Technology drives exploration. While the Moon is not the perfect testbed for Mars exploration, however some technologies match well, such as in-space assembly, for which there are already contracts in place. Some critical technologies that apply to Mars include landing heavy payloads, which can be tested on Earth. Current technologies can only be extrapolated to 1.5 metric tons, while the need will be for about 20 metric tons. Advanced propulsion is another area that will need additional work.

For Fiscal Year 2020 (FY20), the White House proposed a $1.6 billion supplement for NASA. Of that, $132 million was for space technology activities; some of this will go to Small Business Innovation Research (SBIR). Other activities include Solar Electric Propulsion (SEP). Congress is still addressing this, and the House has about $800 million for the NASA supplement, distributed differently from the request. The Senate is at $1.08 billion. Overall, it looks good for STMD, and Congress recognizes the Artemis mission to the Moon, even if it does not fund the entire request.

Advanced communications and advanced navigation are being done in partnership with the Space Communications and Navigation (SCaN) program. The expertise is at SCaN, while STMD does flight terminals, which is the case for Deep Space Optical Communications (DSOC). The Air Force is providing encryption and launch services. STMD has a CubeSat demonstration with SCaN, and the Human Exploration and Operations Mission Directorate (HEOMD) is providing the launch.

Mr. Free asked about Mars sample return in SMD. Mr. Reuter said that the thrust is to operate the mission with Mars 2020 technology. Dr. Mary Ellen Weber asked about the status of CFM. Mr. Reuter said that STMD has been working on CFM at the subsystem level for a couple of years. It has been delayed but is ongoing. There was a flight demonstration cancelled before he came to STMD. Further work on a major demonstration remains an open decision. There is international interest, as well. The next Tipping Point solicitation goes out in January and could include CFM. Dr. Weber said that she understood that CFM is needed for Mars. TI&E was disappointed to see its delay. She asked if the urgency had been restored. Mr. Reuter said that the HLS proposals will need to come in before he can answer that definitively. A demonstration could occur in the 2024-26 timeframe, but he was not sure. The transport systems for Mars concepts could include CFM, but there could also be a need for long-term storage of hydrogen.

Dr. Weber then observed that for SEP, STMD is getting budget increases after years of decreases and directed spending. This is a big win for STMD, and she wondered if NASA appreciated STMD's work in this area. SEP would not be developed without STMD existing as a separate directorate, and it is important that that be acknowledged. Mr. Reuter said that in late spring, the decision was made to keep STMD as a separate directorate. He then became the AA after having been the Acting AA. NASA has a federated team of Deputy AAs from the mission directorates; this team meets several times per week. There is only support right now for having STMD as a separate mission directorate. This goes beyond the lunar thrust to have more activities supported. The budget has almost doubled in the last

several years with essentially the same organization, so STMD is looking at what it should be doing that might not be happening. It makes a difference for him to no longer have "Acting" in his title, as he can make solid decisions instead of deferring them. The Deputy AA is the federated team lead and supervises many people. Mr. Reuter hopes to add two program directors soon.

Acquisition of human exploration services is a NASA concern. The Agency has a large workforce that it must keep trained in order to use their expertise. STMD will study whether there is a role for the directorate in this. The plan submitted to the White House for the FY21 President's Budget Request (PBR) is embargoed. It addresses areas of significant growth, such as surface mobility devices for humans, which will differ from rovers.

There are four technology areas for lunar exploration. "Go" encompasses rapid, safe, and efficient space transportation; "Land" is about expanded access to diverse surface destinations; "Live" covers sustainable living and working farther from Earth; and "Explore" addresses transformative missions and discoveries. Within "Go" are SEP, thruster advancement for low-temperature operations in space, Nuclear Thermal Propulsion (NTP) technologies, CFM, the Green Propellant Infusion Mission (GPIM), and Rapid Analysis and Manufacturing Propulsion Technology (RAMPT). Some of these will involve infusion and/or require demonstrations. One potentially large market could be small satellites. The Deep Space Atomic Clock (DSAC) could be retrofitted later. This is not top-down, however. SMD has had some technology development and demonstration issues that fall in this area. HEOMD put out a call for a precursor HLS. STMD has picked up a lot of refueling activities. Mr. Reuter listed some of the awards, which are now being coordinated.

For "Land," Mr. Reuter listed navigation Doppler LIDAR, Mars Entry, Descent, and Landing 2 (MEDLI2), terrain-relative navigation, Low Earth Orbit-based Flight Test of an Inflatable Decelerator (LOFTID), and the Safe and Precise Landing Integrated Capabilities Evolution (SPLICE) project as elements. Some of this work is being done with HEOMD. Dr. Weber observed that the inflatable concept was dropped some time ago in favor of parachutes, which did not work. Mr. Reuter said that no parachutes are in the plans now. The focus is shifting to retro-propulsion. This is the only Mars-unique EDL. Dr. Weber explained that TI&E had had a briefing about all of the technologies needed to get humans to Mars. She was hearing that even though EDL requires a long lead time for a solution, the only real work is on the inflatable, and the Moon is now the focus. She wondered if this might be a risk, given the long lead time and the fact that NASA is not investing in the area. Mr. Reuter said that NASA is investing in the low Technology Readiness Levels (TRLs). Much of this is budget-dependent. EDL has one of the longest timelines. This is an opportunity to test one of the highest-risk areas in a Public-Private Partnership (PPP). NASA is looking forward in this area, but the budget is not certain. It is possible there will be a 2030 uncrewed cargo mission to Mars, followed by a crewed mission around 2035 or so.

In the "Live" area, STMD is working on lower TRL items like in-space manufacturing, ISRU, and more. The Johns Hopkins University Applied Physics Lab (APL) is helping to put together a plan for a consortium in this area. Dr. Weber said that kilopower requires weapons grade fuel, which is a concern. Mr. Reuter said that NASA demonstrated a 1-kw system with the Department of Defense (DOD), which went well. Next will be a 10-kw capability demonstration. The Department of Energy (DOE) is leading a study, and some of its labs are looking at what that design would be. The focus is on high- and low-enriched uranium (HEU and LEU). At the moment, there is not a mid-sized lander, but the HEU system could fall in that area. SMD is testing it. An LEU system is not impossible. DOE has advisory input and commercial organizations are also involved. NASA is getting the data to make an informed decision. Reuter believes they can probably make an LEU system work.

Within the "Explore" area are activities such as DSAC, surface robotic scouts, small spacecraft demonstrations, laser and optical communication, bulk metallic glass gears, and others. The SPIDER mission was previously Dragonfly and is now part of Restore-L. FabLab, a fabrication laboratory for recycling and printing in space, has had an issue in-orbit after working well on the ground. The team is troubleshooting. Such problems are among the reasons for testing. Mr. Reuter observed that TI&E had previously discussed much of the communications and navigation work. There were many lunar and Mars exploration accomplishments in FY19. In the last few months, there have been about 70 new starts and awards. The Tipping Point program made 14 awards in 2019, many of which focused on the lunar surface and space. There were 19 Announcement of Collaborative Opportunity (ACO) awards made over the summer. NASA provides the technical expertise and facilities, with center involvement. Both Tipping Point and ACO awards help NASA reach partners doing landers and other activities. Mr. Reuter listed nine Broad Agency Announcements (BAAs) for ISRU work. Work on composite technologies for exploration is being completed.

Mr. Reuter presented data on proposals, partnerships, projects, and other measurements since 2011. STMD is consulting Congress about the growth of SBIR with the increase in the budget. One thought is to go straight to Phase 2 and $5 million awards, which some agencies can already do. The Small Business Administration (SBA) and Congress must approve this, and while the White House agrees, the change is unlikely to be ready for the next cycle.

Lunar Surface Innovation Initiative (LSII) Update

Ms. Niki Werkheiser, LSII Lead, explained that the strategic technology investment focus is on exploration, with the goal of humans on the Moon again by 2024 with a sustained human presence by 2028. LSII uses the Go, Land, Live, Explore construct that Mr. Reuter just discussed, focusing primarily on Live and Explore. The Initiative is intended to spur creation of the necessary novel technologies for lunar exploration, including in-house expertise, competitive programs, and PPPs. LSII is not a program itself, but works across STMD programs, also collaborating with other parts of NASA, other government agencies, industry, international agencies, and academia. For this, NASA needs a robust acquisition strategy, which is the thrust of what LSII is trying to do. Budget realities call for phasing and prioritization. The Initiative works closely with HEOMD and SMD.

The six focus areas are: ISRU, sustainable power, extreme access, surface excavation/construction, lunar dust mitigation, and extreme environments. Many of these are cross-cutting and involve interplay among stakeholders. STMD's objectives are to retire risks through technology demonstrations. The work should not involve additional foundational technology development. Mr. Free asked about CFM. Mr. Reuter said that CFM can be part of the work, but it is not exclusively surface work. Ms. Werkheiser agreed, noting that interdependencies and interplay are factors.

The lunar ISRU development and demonstration timeline has three phases: reconnaissance, prospecting, sampling; resource acquisition and processing; and pilot consumable production. LSII is using a leader/follower model. As an example, Ms. Werkheiser described ice mining, specifically the Polar Resources Ice Mining Experiment (PRIME-1) on Commercial Lunar Payload Services (CLPS). The 2024-26 timeframe will involve ice mining and ISRU subsystem consumables and extraction demonstrations. There are a lot of discussions involving if/then constructs, and what is actually discovered. The discoveries can inform further effort. Therefore, it is important to be asking the right questions. The scalable pilot ISRU systems for consumable production will be closer to 2030 and beyond, but LSII is talking about what that means and how it could be executed.

For lunar surface power, STMD is doing technology development to provide continuous power through both day and night for lunar surface missions. Technology development projects underway include power generation and regenerative fuel cell for energy storage, among others.

Collaborative leveraging of industry and academia includes BAAs, Centennial Challenges, a NASA Innovative Advanced Concepts (NIAC) Phase III award to a researcher at Carnegie Mellon, and a worldwide technology search through the NASA Center of Excellence for Collaborative Innovation (CoECI). An approach similar to crowdsourcing has led to some novel approaches, such as a portable energy storage effort now in formulation. Finally, SBIR and Small Business Technology Transfer (STTR) awards can feed into LSII. The Initiative is using a University Affiliated Research Center (UARC) as the LSII system integrator. The NASA Acquisition Strategy Council approved STMD using the APL contract to initiate this task for a feasibility assessment on use of UARC for this purpose. LSII has selected surface power and ISRU as cross-cutting areas.

Ms. Werkheiser then described the Lunar Surface Innovation Consortium, which seeks to keep the United States at the forefront of lunar exploration. The consortium will have APL submit recommendations to STMD in November, followed by an Acquisition Strategy Council review in December and kick-off in January. NASA needs to clearly articulate needs and requirements without being prescriptive. Mr. Free said that he appreciated that approach. He asked for confirmation that the consortium comes together with NASA and industry spelling out their respective needs, does an evaluation, and turns it over to STMD to determine what warrants funding. Ms. Werkheiser said that that is the case, noting that each NASA Center participates. This is a continuing dialogue with individual meetings with companies and academia, resulting in extraction of thematic areas. It will be a mix of internal and external efforts. APL is examining models that could be applied. While the initial focus is on the United States, it will eventually encompass international entities as well.

Office of the Chief Technologist (OCT) Update

Mr. Al Conde, OCT Strategic Integration Office Lead, focused his presentation on two areas: the Strategic Technology Integration Framework, and the 2020 NASA Technology Taxonomy. OCT is an advisory office. There is a Chief Technologist at each NASA Center, and the Office also relies on the NASA Technology Executive Council (NTEC), which includes mission directorate AAs. In addition, there is an NTEC working group, and detailees are brought in from each center to help expand the dialogue. The NASA technology portfolio for FY17 gives a sense of the programs through which the funding is disseminated. Recent milestones include NTEC's approval of proceeding with the Framework. The Council directed NASA to collect the first round of strategic data from the mission directorates. In addition, TechPort was configured to accept Framework Data.

The technology integration framework includes four steps for the mission directorates to follow: mission outcomes; technical challenges; strategy for development; and technology investment. Mr. Conde gave examples of each. The timeline is notional to indicate the amount of time needed and whether the step addresses a mission or a capability. OCT creates the framework and ensures that the data going into TechPort meet the criteria, but the mission directorates determine the investments and the strategies. This helps ensure that there is not just one route to achieving the need. The steps outline what needs to come together, and the sequence. This allows the mission directorates to integrate between their programs and with each other. It can also help eliminate inadvertent redundancy. The strategy is static but needs to be updated.

Dr. Weber asked if the Framework is dynamic enough in light of the new focus on Artemis, and if it can change as needed. Mr. Conde said that it looks at what is needed, and communicates the effort and direction. As for timing, OCT wants it to represent what the Agency is thinking. The mission directorates will determine who does these activities. Mr. Free said that it seems a lot for OCT to own this. He was concerned about integration, for example. With the depth involved, there is a delicate balance of information. The result is that someone has to own an architecture. Mr. Conde replied that OCT is integrating activities but not doing them, collecting inputs at a high level so everyone understands where NASA is headed. The strategic component is important, but this is not about the critical path. This is guidance, not accountability, which is in the mission directorates.

The Framework has a good budget, though it could always use more. It provides greater visibility, informed by mission directorate needs, and leads to a tighter coupling of needs and technology investment. It also aligns technology investments to future mission needs. Each mission directorate uses different processes to reach each of the four steps. The framework helps them develop and maintain a practical strategic technology investment plan. There are distinctions between users and developers – the latter focus on mission directorate needs, while the former identify strategic capability needs. The Framework shifts NASA to a more strategic approach as opposed to tactical. This is essentially about communication to facilitate collaboration, and contributes to efficiency.

STMD has modified TechPort, which has some gaps. The goal is to have quantifiable information. Techport lists more than 1,500 technologies, while the Framework will focus on a few dozen technology challenges that NASA is pursuing. The first cycle of mission directorate data is being uploaded to TechPort, which will standardize mission directorate strategic technology reporting across the Agency. Dr. Kathleen Howell asked if the tool also addresses opportunities for infusion of technologies that have met their goals. Mr. Conde said that if the need is expressed, the TechPort would tap into that. He expects this to encourage infusion. This looks at capabilities rather than technologies.

Mr. Free said that TechPort is viewed more as a repository. This could feel like overhead to the mission directorates, which could constitute a big hurdle and be viewed as a database that needs to be populated. Mr. Reuter said that it has improved as a data source. The goal is for TechPort to contain a substantial amount of information. It has proven useful in querying the activities centered in specific geographical areas, as well, which is helpful with Congress. Mr. Free speculated that financial people could use it, too, and advised OCT to think creatively about how to market it. It could prove more useful beyond the mission directorates. It might be part of the cadence of a year and a program. Mr. Conde explained that it will include goals and descriptions, then the technology challenge, and an image for the strategy. There will be a slight overhead, but many organizations already manage this way. This starts the conversation on where to go and identifies what is not being done. OCT aggregates what the mission directorates decide to do.

Mr. David Miranda, a detailee who worked on the 2020 NASA Technology Taxonomy, explained that the purpose of the taxonomy is to communicate the Agency's technology portfolio in 17 areas. He gave a brief history of the taxonomy, noting that a 2015 update included aeronautics. The 2010-15 roadmaps had two key features: technology roadmaps, and the Technology Area Breakdown Structure (TABS). In 2017, OCT found that almost 80 percent of NASA organizations developed their own roadmaps. However, these organizations also found TABS to be useful. Therefore, OCT decided to retire the roadmaps and replace them with the Framework Mr. Conde just discussed. Now TABS is refocused to be a discipline-driven technology taxonomy.

OCT asked the NASA Center Technology Council (CTC) to revise the 2015 TABS. The first draft came in during December 2018, followed by two reviews, one internal and one public. The latter was completed over the summer, and elicited over 1,700 comments from the community. All of the comments were individually reviewed and dispositioned by subject matter experts from throughout the Agency, and were accepted, rejected, or modified. Mr. Miranda described how some areas within the taxonomy evolved. For example, "launch propulsion systems and in-space propulsion technologies" became "propulsion systems." Other areas are new, and the taxonomy is no longer strictly space-based.

The next step is getting it out. OCT has been working with internal and external stakeholders to make sure they know what is happening and can make comments. The team has done presentations, webinars, posters, brochures, and more to promote the Taxonomy website and TechPort. There have been internal and external crowdsourcing challenges as well, which are part of the social media effort. TechPort has a public-facing aspect that is searchable for fields such as projects, person, taxonomy areas, and more. The 1,700-plus comments came mostly from NASA, but also DOD, the public, industry, etc. The National Academies of Science (NAS) was invited to comment on the Taxonomy, but, as Mr. Conde explained, there is no plan to go to them with the strategic framework. Mr. Green said that STMD will need to think about this, because the roadmaps were approved by NAS and enabled community buy-in. Dr. Weber questioned the use of the term "taxonomy," as many people do not know what it means, and the TX abbreviation is most commonly associated with Texas. Dr. Howell added that the Global Technology Roadmap is still called that, but Mr. Miranda said that it would be using this taxonomy.

Synthetic Biology/ The Center for the Utilization of Biological Engineering in Space (CUBES) Update

Dr. John Hogan, Synthetic Biology Program Manager, explained that this is a small project with a lot of great things coming from it. Primarily, the effort is trying to move biology forward at NASA. CUBES is a Space Technology Research Institute (STRI). Dr. Hogan described the differences between the needs on ISS and Mars, many of which involve biology. To sustain future missions, NASA will rely heavily on ISRU and biomanufacturing technologies. Closed-loop life support, food production, and space medicine are areas of focus. Food and medications have shelf-life issues, which is why NASA requires the capacity to produce them in space.

Biology is quite different from physical and chemical systems in that it is regenerative. In addition, it is often scalable and programmable, precise, and sometimes the only route of production, as with protein. The possibilities for synthetic biology are starting to grow and can be quite amazing. Some of the space-based research challenges are general challenges that are extremely important for sustaining life in space. It will be important to minimize both inputs and wastes, and to purify. Another need is to reduce and consolidate, store, and reanimate. A 5-year life span is quite difficult to achieve for many foods.

The Game Changing Development (GCD) program is funding work at NASA's Ames Research Center (ARC) on BioNutrients and CO_2-based manufacturing. One of the current goals is to demonstrate beta-carotene. A 5-year program on the ISS will demonstrate stability, nutrient levels, and safety. Plans are to disseminate the results of work on the genomic aspect of long-lasting molecules to the community. The program is also testing treatment of the bio-organisms and looking at gene expressions, leading to knowledge of potential hosts. These projects launched to the ISS in April. While experiments currently use a hard container, the goal is to use bags. Early sample analysis has shown some long-term survival. The CO_2-based project will enable making a media for the bionutria. While the demonstration uses substrates, the effort will move to a more complex product while also

making it smaller. Other work involves the bioreactor development and various different organisms. There is a pull on this, and by the end of FY21, NASA hopes to have components that are space-compatible.

The goal of the CO_2 Conversion Centennial Challenge is to use physical chemical systems to convert sugars to feed microbial manufacturing operations without using biological materials. Phase 1 was completed with five awards, and Phase 2 has begun. Dr. Hogan noted the weight factor, adding that glucose is the gold standard. NASA seeks to drive the ability to form all kinds of chemicals, even beyond biomanufacturing. Mr. Free said that the NASA Human Research Program (HRP) has a good description of the challenges needed for human spaceflight, and asked if the Synthetic Biology Program had anything that maps to the HRP work. Dr. Hogan replied that while the mapping was not formal, the Program is increasingly cross-cutting. This is a new program that launched in April, and it will take a while to disseminate the information and organisms.

Dr. Hogan described CUBES, which TI&E had heard about previously. The lead institution is UC Berkeley, with five collaborating institutions. The award is for five years at $3 million annually, to support biomanufacturing for deep space exploration with an autonomous system that NASA hopes to demonstrate. There are four integrated research divisions: Systems Design and Integration (SDID); Microbial Media and Feedstocks (MMFD); Biopolymer Bio-Manufacturing (BBMD); and Food and Pharmaceutical Synthesis (FPSD). Dr. Hogan went on to describe progress in each of these.

SDID is becoming very integrated with NASA and has done a biomanufacturing-driven reference mission architecture with Martian climate and environmental models. The Division has an optimized decision-making system and is working on waste recycling. MMFD is converting CO_2 into microbial feedstock and has shown this is possible with 2 percent nitrogen. The Division is also using bacterial biomass to feed plants. BBMD is using methane for bioplastic production. Work with biopolymers is helping to determine which ones warrant production. FPSD has a number of projects. This team has learned that adding far-red wavelength light makes plants grow larger, for example. Some lettuce strains have been engineered to have a bone-regenerating therapeutic protein. The Division also worked on engineering spirulina for production of acetaminophen.

Now at its midpoint, CUBES is on schedule. The team is looking at six technology coupling integration examples now. This will be the most extensive integration of its kind. Dr. Hogan noted the STMD Early Career Faculty Program, STTR efforts, and some notable conferences. The Program is starting to help with the HRP food system road-mapping effort. Mr. Johns asked if the STRIs are meant to be self-sustaining after funding ends. Mr. Reuter said that STMD intended that the length of five years would keep them going long enough to have other activities, but this discussion will occur at the end of the cycle. Dr. Hogan said that the STRIs can go after other venues, like the commercial sector, after the five years. Industry is presenting and interfacing at the seminars, and some companies are asserting themselves. NASA still wants to provide guidance.

Nuclear Thermal Propulsion Update

Mr. Rick Ballard of NASA's Marshall Space Flight Center (MSFC) provided an update on NTP. The focus has been to develop risk reduction technologies to show that NTP is a viable candidate for in-space transportation, specifically looking at the feasibility of a LEU-based engine with cost and schedule confidence. A flight demonstration study is inviting industry to help evaluate NTP concepts, including missions and additional fuel forms. A partnership with the DOE has been extremely fruitful, and the team is trying to identify other areas for

collaboration. The feasibility analysis has been focused on whether there is sufficient infrastructure.

There are three fuel element test facilities: Compact Fuel Element Environmental Test (CFEET), Nuclear Thermal Rocket Element Environmental Simulator (NTREES), and Transient Reactor Test Facility (TREAT). While 34 of the 42 feasibility criteria were rated Green and eight were Yellow, fuel element testing has dropped to Red. The flow-down is such that it is not possible to move forward without a viable fuel candidate. Rather than say there is no fuel element, however, it is more accurate to state that the issue is fuel composition. The temperature capability that would be needed is much higher than would be of interest to DOE. Mr. Reuter said that DOD could withstand a lower performance than NASA can for a human-class Mars mission. Time is a factor. The Defense Advanced Research Projects Agency (DARPA) has a similar objective, but it could be that NASA takes the flight demonstration to where it is almost a plug-and-play. The question is whether to set a requirement reflecting a goal or an engineering criteria. He believes the former is better.

Mr. Ballard said that NTP is extremely coupled with the environment, so the work has to be collaborative. The program has an Idaho National Lab (INL) person embedded. Mr. Free asked when NTP will be for flight versus for study. Mr. Ballard said that there are things NASA can do separately, but there are combined effects. He described the fuel element development status. Previously, the Packed Powder Cartridge (PPC) was the main approach. The cold end was tested in June, and there was separation and a power system fault resulting in an unintended cool-down. There were issues with refractory metals on the hot end. The Design Independent Review Team (DIRT) panel recommended that the program cease testing the PPC fuel development and focus resources on alternate Spark Plasma Sintering (SPS) reactor design development for the remainder of the project baseline.

Mr. Ballard then described SPS Cermet FE development at MSFC, which will deliver a 16-inch surrogate test article for NTREES testing in November. The team is looking at an initial fuel development study and fabrication demonstration for higher temperature multi-use TRri-structural ISOtropic (TRISO) or Coated Mixed Carbide (CMC) fuel development. This is being done in conjunction with the INL. Also in collaboration with DOE and INL, NASA has put a radioisotope in a fuel sample, a significant activity that demonstrates TREAT's ability to simulate prototypic stresses on fuel and evaluate fuel performance during rapid heat up and thermal cycling conditions. The team has completed the six-test campaign, though an additional test is possible. This is NASA's first NTP test since the early 1970s. Mr. Ballard then reviewed the remaining challenges.

The flight demonstration study was initiated in response to Congressional language. The objective is to produce sufficient peer-reviewed documentation and briefings to provide STMD with the clarity it needs to study a potential NTP flight demonstration and report back to Congress. There are two flight demonstration options being considered: FD1, which is the nearer term and seeks the earliest available flight hardware delivery, and FD2, which is longer term and emphasizes extensibility and performance over schedule. These are leading to something like a mission concept review. The FD1 study, which allowed a readily available fuel to be selected, began before the industry study. This concept could be done in 5 years at less than $1 billion. The orbit would have called for a large launch vehicle and simpler onboard systems. Both reports indicated that the cost was out of balance with what NASA would get from it, and therefore the team was directed to stop work on it. Although the FD1 concept was considered low technical risk and feasible, it had limited extensibility to an operational NTP system. There is not an out-brief on FD2 because those studies have just begun. However, an NTP system could reduce crew transit time to Mars and increase

mission flexibility, which would enable a human exploration campaign, and so the evaluations continue in the direction of a flight demonstration project.

Mr. Reuter added that NASA is awaiting industry input. The Agency needs high confidence to move forward. Mr. Ballard said that the report should appear in the spring of 2020. NASA has been doing architecture optimization and composed the NTP system requirements, which drive up the fuel element requirements.

Early Career Initiative Overview

Mr. Ricky Howard described the two components of the Center Innovation Fund (CIF) Program: the CIF and the Early Career Initiative (ECI). The goal is to invigorate NASA's technological base and best practices by partnering early career NASA workers and external innovators. The plan was to select five projects in 2019, but the 15 proposals were so good that another unit took on two, for a total of seven. Mr. Reuter noted that STMD wants proposers to know they have a good chance of winning, and therefore seeks white papers first, then asks submitters for proposals.

Mr. Howard explained that half of the NASA workforce is age 50 and older, and roughly a third could retire today, which puts some urgency into accelerating the capabilities of early career workers. The best way for them to gain those capabilities is to run their own projects. STMD is also seeking other management approaches. The initial pilot group of four projects include: LISA-T (Lightweight Integrated Solar Array and Transceiver); HiDyRS-X (High Dynamic Range Stereo-X); OOAAN (On-Orbit Autonomous Assembly from Nanosatellites); and IDEAS (Integrated Display and Environmental Awareness System). Mr. Miranda was on the IDEAS team, and said that the ECI was a great experience, involving a partnership with Florida Tech and a company called Purple Rock Scissors. Mr. Howard then showed the proposals selected in FY18 and FY19, one of which was delayed due to issues with a foreign company.

Precision Targeting of Deployable Entry Vehicles was an FY18 precision landing project that successfully used a hybrid project management system. Another FY18 project is the Orbital Syngas/Commodity Augmentation Reactor (OSCAR), which collects waste gases in order to use the components. The payload will be tested on a Blue Origin flight in December. Smart Habitat Robotics: Manipulation Technology looks at robotics and the use of logistics management. The Autonomous Multifunctional Sensor Platform can develop a low-resource, in-situ multifunctional sensor platform that will enable a broad range of missions across a range of disciplines by printing directly on a substrate.

The FY20 ECI portfolio benefits from the Artemis program and has a sense of urgency. These projects just started and include Development of a Thermal Control System to Survive the Lunar Night, which builds hardware that will go to the Moon. In-Space Assembly of Perovskite Solar Cells for Very Large Arrays would work better in space than on Earth. The Molten Regolith Electrolysis- Starter Device will use regolith to contain products so that they do not affect their surroundings. The JARVIS (Joint Augmented Reality Visual Informatics System) provides display and controls for a space suit. The Extractor for Chemical Analysis of Lipid Biomarkers in Regolith (ExCALiBR) involves a partnership with Shell Global Solutions, Inc. A Mobile Frequency-Modulated Continuous-Wave (FMCW) LIDAR System for Lunar Surface Terrain-Mapping and Navigation is essentially a backpack that does mapping of the person wearing it while also doing a high-resolution map of the space around the person. There is also a modular and reconfigurable manipulation system for autonomous in-space assembly.

The feedback from PIs has been overwhelmingly positive, and each early career proposer gets feedback to help with future proposals. There has been good diversity. It appears that some industry partners will replicate this approach for their early career employees as well.

Discussion and Recommendations

Mr. Johns agreed to give the presentation to the NAC in Mr. Free's absence. The Committee began discussing what to include in that presentation. Mr. Free noted that STMD has made great progress and is coalescing around lunar plans quickly. Mr. Reuter pointed out that TI&E used to push for a sense of urgency, and now STMD has that. Mr. Free wanted to note that TI&E is glad that Mr. Reuter is the official AA and no longer Acting.

Dr. Howell said that the SEP work was critical and STMD had started it early. She suggested making the point that it was important for STMD to start this item with its long lead time. Now they need to think about having Mars on the far horizon. Dr. Weber said that had STMD not had some of the budget cuts, they would be further along on eCryo, which is needed now. It is therefore important to support the message that NASA needs an independent mission directorate for technologies that are critical for the future even before a specific mission. This statement would include both a celebratory note and a cautionary note. Mr. Free thought they should add that mission selection flexibility goes up when there is a strong technology base. This enhances the Agency's ability to be agile.

Mr. Green advised acknowledging TI&E's past recommendations to keep STMD separate, which has been done. Mr. Johns added that it is good to have a permanent AA, robust budgets, and numerous new technologies starting. There had been years with gaps. He also liked the focus on younger workforce engagement. Everything they saw reinforces the importance of the independent mission directorate. He wondered if TI&E could learn how much of STMD's work is Mars-unique. Mr. Reuter said that could be put together. It is not much. Dr. Howell thought it would be helpful to convey this information to the NAC, and note the risk if NASA does not think longer term.

Dr. Weber observed that what gets done is quite well-managed, but STMD has not always been well-funded. She wondered if they might have a presentation on what needs to be done to go to Mars and is not being done due to the budget. It was good to know that someone had the big picture even when the projects were not being funded. If TI&E had that, they could express concern as appropriate. She noted that this was not a recommendation for NAC. Dr. Free suggested getting a presentation on the 2024-28 timeline, noting that Johnson Space Center (JSC) people do not have a list of what they need for 2028, because there is such a rush to get to 2024.

Mr. Free noted that the Technical, Management, Cost, and Other (TMCO) process is very structured. STMD should at least be able to jump to the front of the line and note what has been proven. He wondered about highlighting the synthetic biology work as opening doors and potentially helping with commercialization. Mr. Reuter explained that that work is spread among different accounts. A key STMD strength is its breadth. The same is true of SBIR, and STMD can use the entire budget to attack a problem from multiple directions. Dr. Weber observed that SBIR seems to be directed better now. Mr. Free said that he would like to know the extent to which the Strategic Integration Framework is used, particularly by the lower tiers. Mr. Conde said that that is a concern. NASA wants it to be used rather than being a shadow activity. Dr. Howell said that several TI&E members have never seen TechPort, and Mr. Free wondered how much of the broader community even knows about it. Mr. Conde agreed that there is a need for promotion. Mr. Green said that TI&E could have a demonstration at the next meeting.

Mr. Free said that TI&E had a previous finding on NTP, and he still wants to know the plan. NASA made progress by taking FD1 off the table, and there is a direction, but it still feels far away. Mr. Reuter replied that the NASA Administrator, Mr. James Bridenstine, is talking more about NTP, and it is getting serious attention. There are things in the works, but they cannot schedule flight demonstrations before the technology is ready. Mr. Ballard added that the PPCs always had him concerned. He has worked on propulsion systems for about 30 years. Welding causes challenges, and some were not surprised that there were cracks. In terms of items that are not being done, fuel is the most significant. Mr. Free repeated his call for a plan that would allow tracking. It was noted that NASA did FD1 in order to present the concept. The Agency needs to get to the point of doing a flight demonstration, and these test flights will have a long lead time. Dr. Weber pointed out that there is Congressional direction to consider as well. Mr. Reuter advised putting it aside for the moment. Mr. Free said that it is important to do the assessments and studies as soon as possible, then integrate the results into a plan leading to a human flight with NTP.

Mr. Reuter said that STMD wants to capture the fuel development aspect, which is why the team declared Red on the feasibility. Mr. Free suggested stating that the fuel development path has to be redirected. Dr. Weber asked what TI&E might be trying to accomplish by raising this with the NAC. Mr. Free replied that NTP involves a bigger Agency decision beyond STMD, and other parts of NASA need to be aware and responsive. Dr. Weber wondered if there TI&E should keep telling the whole Agency, given that the project is stalled. Mr. Free thought that was a good point. He wants the single-page plan that is not going to be just STMD. Dr. Weber said that the finding should be clearer to match what he said. Mr. Green suggested stating that TI&E talked about NTP last time, but there has been a setback, and while it is being worked on, a timeline is necessary. Mr. Ballard said that a timeline would help as a driver. Mr. Free added that NASA will always be eight years out from NTP unless someone puts up milestones. Mr. Ballard noted that the industry study will provide more insights.

Dr. Weber asked if the ISS extension to 2024 affects what STMD is trying to do. Mr. Reuter said that it is a concern. ISS is a proving ground, and it is the primary path for some areas, with a lot of demonstrations. When Dr. Weber asked if a recommendation would help, both Mr. Reuter and Mr. Green said that there are bills in Congress to extend it to 2028 or 2030. Mr. Reuter then said that it might be a good time to hear from Engineering about their concerns and services approach. Everyone liked that idea.

It was suggested that TI&E give some of its NAC presentation time to the ECI researchers to discuss their projects. Dr. Weber said that the LSII presentation had a good chart that was otherwise identical to a summary chart of Mr. Reuter's, except it highlighted a few boxes. It shows what has been done and what remains to be done. Dr. Howell thought that would be a good companion to the lunar/Mars chart. Mr. Green said that he and Mr. Johns were going to select some slides. TI&E should have a chart with a few bullets with general observations, and some language on NTP.

Dr. Weber asked if they should bring up eCryo and how the budget has kept NASA from being sufficiently advanced. Mr. Green thought it would be a good idea to say that the STMD investments have enabled progress in a lot of key areas like SEP, but budget inadequacies have kept the mission directorate from doing things NASA will need, such as eCryo. Mr. Free said that TI&E has previously conveyed that message. Dr. Weber noted that a proposed flight demonstration fell off. TI&E's draft finding stated that STMD has achieved many successes, and its investments help enable missions. TI&E believes that sustained technology funding is needed in order to have the technologies to meet aggressive mission

goals for lunar and Mars exploration. STMD has also done a good job aligning SBIR/STTR investments with Agency priorities, and the Committee supports enhancing Phase II.

Mr. Green said that they would also pull in charts on synthetic biology and CUBES, adding a blurb on the STRIs as well. To note the benefits of engaging early career professionals, the Committee decided to start with two charts and note the benefits of the new project management approach.

The NTP finding was to be based on the previous one, which stated that TI&E believes NTP will help reduce crew transit time to Mars and increase mission flexibility, enabling human exploration. Continued work by STMD has brought to light a fuel issue that would not have been discovered otherwise. Recovery from that issue is central to moving forward with NTP development and a future test flight. Ongoing internal and external studies need to be completed in order to have an integrated solution/direction/results around which the Agency can make decisions. The Agency needs to define a projected human to Mars launch from which STMD can set a development flight in order to define a path to that date.

The Committee debated setting a hypothetical launch date of 2035, which would require a demonstration flight around 2027. The finding would state that STMD has to set a path to that demonstration flight that would have to occur in the upcoming budget window. One consideration is that NASA will need time to make design changes as a result of the demonstration. Mr. Green would work on this and send out the charts once drafted.

Adjournment

The meeting adjourned at 5:34 pm.

Appendix A

Agenda

NAC Technology, Innovation and Engineering Committee Meeting
October 29, 2019
NASA Kennedy Space Center
Headquarters Building, Conference Room 6440
Dial-in number: 1-844-467-6272; Pin Code: 102421

October 29 – FACA Public Meeting

8:30 a.m.	Welcome and Overview of Agenda/Logistics Mr. Mike Green, Executive Secretary
8:35 a.m.	Opening Remarks Mr. Jim Free, Chair
8:40 a.m.	Welcome to Kennedy Space Center Mr. Robert Cabana, Director, Kennedy Space Center
9:00 a.m.	Space Technology Mission Directorate (STMD) Update and Discussion Mr. James Reuter, Associate Administrator, STMD
10:15 a.m.	Break
10:30 a.m.	Lunar Surface Innovation Initiative (LSII) Update Ms. Niki Werkheiser, LSII Lead
11:15 a.m.	Office of the Chief Technologist Update Mr. Al Conde, OCT Strategic Integration Office Lead
12:00 p.m.	Lunch
1:00 p.m.	Synthetic Biology/ The Center for the Utilization of Biological Engineering in Space (CUBES) Update Dr. John Hogan, Program Manager, Ames Research Center
1:45 p.m.	Nuclear Thermal Propulsion Update Rick Ballard, NASA Marshall Space Flight Center
2:45 p.m.	Early Career Initiative Overview Mr. Ricky Howard, Program Executive, STMD
3:45 p.m.	Discussion and Recommendations
5:00 p.m.	Adjournment

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
Mary Ellen Weber

NASA Attendees:
Rick Ballard
Robert Cabana
Al Conde
Anyah Dembling
Chris Gerhardt
John Hogan
Ricky Howard
Leejay Lockhart
Dave Miranda
Ashley Nelson
James Reuter, *STMD Associate Administrator*
Niki Werkheiser

Other Attendees:
Stephen Long
Amy Reis, Electrosoft
Elizabeth Sheley, Electrosoft

WebEx:
Ben Allen
Antonella Alunni
Stephen Clark
Sarah D'souza
Jeff Foust
Dave Huntsman
Brett Silcox
Clare Skelly

APPENDIX D

Presentations

1) KSC Overview [Cabana]
2) STMD Update [Reuter]
3) Lunar Surface Innovation Initiative (LSII) Overview [Werkheiser]
4) OCT Update [Conde]
5) Synthetic Biology/Center for the Utilization of Biological Engineering in Space (CUBES) Update [Hogan]
6) NTP Update [Ballard]
7) Early Career Initiative Overview [Howard]