National Aeronautics and Space Administration

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

Hybrid Meeting
December 15, 2022

Meeting Minutes

G. Michael Green, Executive Secretary

Michael Johns, Chair

TABLE OF CONTENTS

Meeting Report prepared by
Elizabeth Sheley

NASA Advisory Council Technology, Innovation, and Engineering Committee

December 15, 2022
NASA's Marshall Space Flight Center

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 Committee members, including those participating online. The NAC had a meeting planned for mid-January, so the TI&E meeting was timely. This has been a big year for NASA and the Space Technology Mission Directorate (STMD), which was reflected in the agenda. Mr. Green thanked Ms. Jody Singer, Director of NASA's Marshall Space Flight Center for hosting the meeting and providing a tour the previous day. He then turned over the meeting to Mr. Michael Johns, TI&E Chair.

Opening Remarks
Mr. Johns welcomed and thanked the meeting participants. He hopes to have two Committee meetings at centers each year, with a third at NASA Headquarters. The agenda was largely responsive to the previous meeting.

Welcome to NASA's Marshall Space Flight Center (MSFC)
Ms. Singer welcomed the Committee members. There is a lot going on at NASA Marshall, and she made special note of the Center's participation in the Imaging X-ray Polarimetry Explorer (IXPE), the James Webb Space Telescope (JWST), and the Orion spacecraft. Marshall has identified technology gaps going forward and hopes to pull in the right people for such projects as Artemis and the Space Launch System (SLS). To adapt to the changing workforce, Marshall is trying new things, such as pairing experienced and early career employees to work in many different operating cycles. The next generation of workers and investment are both important, as is the need to inspire people beyond the big flagship missions. The key is to work on multiple projects and leading-edge activities to grow the workforce and give people the right experience. This includes doing outreach to schools and colleges, which means lots of internships and pipeline activities. NASA needs the people and teams in place to get things done.

Marshall is one of 10 NASA centers. While it is known for propulsion, the work goes beyond rockets. Ms. Singer is trying to make the case that Marshall is a design center, and it is critical to develop in-house capabilities to maintain NASA as a smart buyer. Of the Center's 7,000-plus civil servants and contractors, 80 percent are engineers, and they work at 125 different facilities; Marshall is NASA's second-largest research park. The multiple partnerships reflect the growing number of activities and the synergy required to support a variety of customers. While this attracts a lot of people, there is competition for expertise, and annual attrition is currently about 10 percent. Marshall addresses this by hiring early career and mid-career workers with the right skills.

Ms. Singer described economic impact that NASA has on the nation and that Marshall has in Alabama. The NASA budget is about 0.5 percent of the national budget. Marshall supports every mission directorate, with the largest being the Space Operations Mission Directorate (SOMD). The team on the Artemis I mission did a great job, and part of that involved their relationships with contractors. A lot of hard work went into this, including testing, modeling, and simulations. NASA Marshall was responsible for the software, which was very critical.

This will be handed off to contractors going forward, but it shows that NASA is evolving as it flies Artemis' progressive missions. The agency is finding new ways to do additive manufacturing with the upper stage and will have four engines. This requires a lot of work on modeling and avionics.

Marshall is responsible for landing systems, which relies on synergy among contractors and the other centers. The near-term goal is to support sustained activity on the Moon so that astronauts can live there. The Center has been supporting the International Space Station and coordinates with NASA's Johnson Space Center in Houston on science payloads. This work will be critical in integrating science into Artemis and will call for increasingly complex life support systems. These will have to be a completely closed loop on Artemis. In the science area, Marshall works with Ball Aerospace, international space agencies, and others. The Center did the testing of JWST's mirrors and provided other enabling support. The x-ray telescope facility does a lot of cutting-edge research. The Earth science office helps the nation and the world understand our planet. Key to this are the data, which are applied and provided to users. A crucial capability involves sorting through massive amounts of data to identify what is important. Finally, Marshall does a lot of outreach and curriculum development, working with Historically Black Colleges and Universities (HBCUs), among others. The Center has a strong social media presence as well.

Mr. Johns asked about workforce retention strategies. Ms. Singer explained that what keeps her up at night is the role of NASA, civil servants, and the innovation of partners. The budget is not unlimited, so a healthy balance is key. But with the need for accountability, the question becomes what to make, buy, or rent. There must be a skilled workforce for acquisition and the programmatic elements. This requires a mix of subject matter experts (SMEs) and early career workers getting hands-on experience as part of the team. It would help to have a blueprint and a vision going at least five years forward in order to formulate the right workforce mix. That would let the agency tell people why they want to come to and stay at Marshall. It is important in creating a diverse workforce as well.

Dr. Rebecca Kramer-Bottiglio asked if there might be data on where those who leave Marshall are going, and if there is part of the budget allocated to retention activities. Ms. Singer said that people hold onto and leave jobs for a variety of reasons. She was close to retiring herself, but the pandemic delayed it. There are people for whom that was a factor, and there are those who were waiting for Artemis to launch. The government cannot outbid the private sector, but it can provide interesting work, training, mentoring, etc.

Space Technology Mission Directorate (STMD) Update

Mr. James Reuter, Associate Administrator (AA) of STMD, said there are about 1,400 active projects in the mission directorate. There has not been much news about the budget since the August meeting. Congress is still looking at about $1.4 billion for STMD. He is optimistic that there will be a budget. NASA has maintained consistency of purpose despite changes in administration. The report on the Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID) test was imminent; this mission went beautifully. It was an in-house project, and Marshall did the avionics. Going forward, NASA is trying to find what projects make sense to do in-house. Part of the agency's purpose is to help train the workforce.

NASA's Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) launched in June and has entered its orbit around the Moon. It is a self-powered CubeSat demonstrating autonomous operations. After the third burn, a thruster valve had issues that led to spinning of the spacecraft, though it remained on the right trajectory. A number of small companies managing the mission addressed the problems one by one and eventually worked around the valve issue to put it back into operation. NASA will go through this for lessons learned. CAPSTONE has been named small spacecraft of the year and has done great work for a small satellite (SmallSat).

The Lunar Flashlight, launched December 11, is another CubeSat. It will go into an orbit close to the Moon and deploy Near InfraRed (NIR) sensors to help identify water and regolith. The Laser Communications Relay Demonstration (LCRD) has been completed and delivered. It will conduct two-way communications. Roll Out Solar Arrays began as a project in the Small Business Innovation Research (SBIR) program, then moved to Game Changing Development (GCD) in order to reach Technology Readiness level (TRL) 6. There is a lot of interest in this for both the space station (where it has been deployed) and the commercial sector. A SmallSat project called Terabyte Infrared Delivery (TBIRD) launched in May and could provide the fastest downlink ever. The Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) is going well.

There were lessons learned from the Deep Space Optical Communications (DSOC) project and the Psyche mission. Among the DSOC challenges was a delay in software testing. It raises the question of whether teams are really communicating and coordinating as much as they should. A Starlink mission communications project is in the works to demonstrate autonomous operations. There are deployable structures on an advanced solar sail system being tested. In the technology maturation area, STMD has eight payloads ready to fly over the next year or so. Among these is the Polar Resources Ice Mining Experiment-1 (PRIME-1), a drill for water ice. Additional technologies selected through the Tipping Point program, like a robotic hopper, will be demonstrated in the coming months/years.

A challenging project was the Thruster for the Advancement of Low-temperature Operation in Space (TALOS). This has been adopted on some commercial projects because it is small and offers good performance. Despite some challenges, this has gone forward; it is on the critical path for NASA and enough progress has been made to retain the flight. The Lunar Surface Innovation Initiative (LSII) is going strong after kick-off in February 2020. NASA wants to engage the country in this. JHU's Applied Physics Lab (APL) has agreed to be the system lead and to also lead a consortium with over 700 organizations from every state and 46 countries. STMD does not fund through the consortium, but it is a way to communicate and bring new groups into the NASA circle. There are two large meetings each year, along with workshops. Mr. Reuter described a consortium meeting focused on excavation.

Recent awards include high-performance spaceflight computing, awarded to a commercial company as a fixed price project with a deliverable in three years. Vertical solar array awards were given to three companies to further advance the technology. This will involve putting a vertical solar array at the lunar South Pole. The Tipping Point budget has been an issue, but support from other mission directorates has helped. STMD has obligated over 98 percent of those funds and slow-rolled the selections using a two-step proposal process. This could be a further issue in 2023. In addition, this is the first time STMD has had approval to use funded Space Act Agreements (SAAs), which opens up some possibilities.

Dr. Michael Gazarik asked about the timing of the Psyche report, noting that many in industry and the community are looking forward to its lessons learned. Mr. Reuter replied that the agency as a whole is studying the report and it is not ready for broader release just yet. Among the many topics involved is the environment for communications. Dr. Gazarik noted the importance of safety nets to help teams move forward.

Mr. Reuter explained that STMD has been trying different things with the phased proposals and now budgets to assume everyone is going forward. There has been an effort to implement a much shorter process as well. Through the Ignite program, 12 small business awards were made outside of the regular SBIR process in order to focus on higher priorities in a few select areas. Dr. Kramer-Bottiglio asked why there are not just separate proposals and if any teams decide to not go to the second phase. Mr. Reuter explained that STMD just started this. Mr. Andrew Rush asked about the progression of SBIR awards, based on what has been seen thus far. Mr. Reuter said that there are some restraints, but there are efforts to take them forward in the two-step process. Dr. Kramer-Bottiglio asked about STTRs, and Mr. Reuter explained that Ignite is a pilot program for SBIR only at this point. Mr. John Dankinich added that the extra couple of months for new awardees helps ensure that there is a user for the technology being developed. Mr. Rush asked if the proposal timeline created a blackout period. When told that it did not, he suggested that there be more clarity on this. There are 12 of these initially, and Mr. Reuter expects them to all go to Phase 2. There have been instances of awardees in other programs opting out of proposing to Phase 2, but this project is not to that point yet.

Regarding the Space Technology Research Institutes (STRIs), six have been established and two more will be announced in early 2023. Much of the focus is on infusion. In addition to extending the Institute for Ultra-Strong Composites by Computational Design (US-COMP) through 2024, STMD also has pending selections in quantum sensing and in certification of additive manufacturing. NASA Innovative Advanced Concepts (NIAC) projects have generated a lot of interest, and among the possibilities is a gravitational solar lens. For the Watts on the Moon power Centennial Challenge, there have been seven awards made for Phase 2. Other efforts include a Break the Ice challenge and Deep Space Food challenge, the latter being done in conjunction with the Canadian Space Agency. The strategic framework for Moon-to-Mars is going really well. This effort has four major thrusts and has identified priorities for the future. The ASCEND conference in October resulted in great feedback. Mr. Dankinich noted that there was great value in bringing together community members who did not know what the others were doing. This has created partnerships to help with NASA gaps and will go beyond what the agency needs. Mr. Reuter expressed the hope that the conference will be annual, resulting in a process sort of like the Science Mission Directorate (SMD) Decadal Surveys (DSes). He would like to have the priorities set to guide investments.

STMD leads lunar infrastructure but participates in other areas such as transportation. The STMD social media followers are numerous. NASA will release the next graphic novel in the *First Woman* series in 2023. A challenge for graduate student projects resulted in awards to 57 teams, all of which delivered their experiments. Dr. Kramer-Bottiglio asked how many NIAC proposals translate to awards, noting that it might be popular as a result of not having specific topic. Mr. Reuter said that it is very competitive, at about an 8% selection rate. Dr. Michael LaPointe, NIAC Program Executive, added that there are typically about 300 initial proposals, and out of that STMD will invite 110 to 120 full proposals, awarding 14 to 16 per year for Phase 1.

NASA Nuclear Systems Update

Dr. Anthony Calomino, Space Nuclear Technologies Lead for STMD, and Mr. Jason Turpin, Project Manager for Space Nuclear Propulsion at Marshall, updated the status of nuclear systems projects. Dr. Calomino explained that these investments have been in place for a number of years, with the goal of providing sufficient energy for astronauts to live in space and operate in extreme environments. There have been some changes: the program is now looking at Low-Enriched Uranium (LEU) fuel forms, which have strong commercial interest. He reviewed the benefits of having a nuclear capability in space. NASA is collaborating with other federal agencies in some areas, such as the Defense Advanced Research Projects Agency (DARPA) on national security. The effort will require driving the mass and volume down, and some of these technologies will find their way into terrestrial operations.

Both Congress and the White House Office of Science and Technology Policy (OSTP) provide guidance and direction in this arena, and NASA must respond to the directives. NASA has issued five reports to Congress and one to OSTP just this year, identifying how the agency will use nuclear power in space. NASA belongs to a group of federal agencies that seeks to delineate roles. National Security Presidential Memo (NSPM) 20 provides tiers of risk and identifies who can authorize launches. This power had been held by the White House exclusively, but now some launches can be approved at the agency level. Any mission using weapons-grade uranium goes to the President, but most NASA missions will be Tier 2, which can be authorized by the agency administrator. To a certain extent, the tiers drive the design. Dr. Calomino described which projects are led by which entities, noting that U.S. Space Force (USSF) involvement has grown. There is an effort to standardize fuel manufacturing. The Department of Energy (DOE) has expertise and is part of the team.

NASA's Fission Surface Power (FSP) strategy goes beyond the lunar surface, though that is the more immediate need. Mars is also a goal. Part of the strategy involves transitioning technologies to industry as part of an effort to build this capability in the private sector. Interested companies range in size from corporate giants to smaller companies and venture capital interests. Dr. Mary Ellen Weber pointed out that the Department of Defense (DOD) has an office that partners with venture capitalists, with the focus on keeping key technologies in the United States and avoiding adversarial investments. This area might be attractive for that office. Dr. Calomino agreed. He explained that the change from 10 to 40 kWe is also a better fit for industry, as well as a better investment of NASA resources. There will be two phases, the first a design concept for LEU that will help to understand the landscape, engage with partners, and inform Phase 2.

The three FSP efforts funded at this point all pair large and small companies. Only a few months in, these partnerships are already demonstrating progress. The contracts include stretch goals in order to identify the key capabilities that will be the highest risk and require NASA investment. There are very few requirements, however, as the agency is only looking at performance metrics in order to enable innovation. Phase 2 will be a notional 5-year contract, and a possible third phase will include a launch. The Idaho National Lab (INL) and DOE are managing this, allowing cost-sharing with industry.

Dr. Calomino then reviewed each of the three contracts. They will have to identify which fuel forms to use. DOE has tutorials on design and is developing industry engagement plans. NASA has been investing in Stirling engines for some time and will now shift to looking at how to mature Brayton power conversion systems to the same level. The contract mechanism essentially has NASA buying the design. Some companies bring in their own intellectual property, which the agency will respect, though the companies will need to identify boundaries. What is not yet understood is how to engage elements of the technology community that might want to be part of Phase 2. NASA wants industry to deliver a cost and schedule model.

Mr. Turpin then contrasted Nuclear Electric Propulsion (NEP) with Nuclear Thermal Propulsion (NTP). NASA has done what it can with chemical propulsion and must now seek ways to gain more thrust with less fuel. NEP has the highest efficiency though not the greatest thrust. NTP doubles the best thrust available from chemical propulsion. LEU is highly feasible for both NEP and NTP to meet NASA purposes, so the agency is pushing forward with the two systems. NASA hopes to leverage partnerships to develop the systems needed for Mars. From the NEP perspective, this means collaborating with USSF, while DARPA is the better partner for NTP. The intent is to grow both systems.

Mr. Johns asked about the funding plan for NEP, given that it is viewed as requiring more investment. Mr. Reuter said that NASA works through what the agency believes is needed and tries to get it funded. The next priority is NTP, according to Congress. Other agencies have the same priorities. NASA will not get everything it wants. Mr. Turpin agreed, noting that there is a lot of overlap, so they are trying to be smart about leveraging this. Mr. Reuter added that NASA hopes to take advantage of the work that has been done.

Mr. Turpin then listed the five critical technology elements (CTEs) within the NTP system, noting how they all tie together. NTP pushes temperatures to the limit more than NEP does. NASA is currently reviewing a draft NTP Technology Maturation Plan (TMP), which will guide development and investments. The implementation strategy for NTP starts with identification of what is possible and where the gaps lie. Cryofluid management (CFM) is important to everything they do, and also applies to NEP. At this point, the NTP engine appears to have traditional heating and controls. This engine will be heavier than others, but the deficit is made up by having less propellant. A graphic depicted the reference design for the reactor system. STMD is involved in every part of reactor development. A lot of work remains in order to reach lower temperature levels. Testing is a challenge, and three companies are involved in reactor development.

There are unique issues associated with the radiation environment. A graphic showed the many paths being followed to achieve a human-rated engine. Non-nuclear reactor fuel testing has been going on at Marshall facilities, including the Nuclear Thermal Rocket Element Environmental Simulator (NTREES) and Cermet Fuel Element Environment Testing (CFEET). Nuclear testing is being done at MIT and the INL Transient Reactor Test (TREAT) facility. Mr. Turpin described NTREES, adding that the high power density is a challenge, as is the thermal gradient. He then discussed some of the testing at TREAT.

The Phase 1 contracts for the reactor were awarded in August of 2021 and have been extended another year to address the many remaining issues. There are a lot of options being developed in parallel; these will be narrowed down at some point. The current focus is on fuel fabrication and testing. In summary, the program is heavily embedded with DOE and the national labs, while partnerships with industry continue. There is significant interest in micro-reactors and a great deal of enthusiasm. Dr. Calomino added that the program is being tactical in its industry engagements, taking a nonstandard approach that provides a lot of latitude. He likes partners to have a commercial interest in the capability.

Dr. Kurt Sacksteder of NASA added that there are other areas with potential for leveraging technologies, with systems that could have a place in agency programs despite not being developed for space. It was noted that autonomous operation is a big area of interest for commercial reactors.

Technology Demonstration Missions: Cryogenic Fluid Management and Low-Earth Orbit Flight Test of an Inflatable Decelerator Updates

Ms. Trudy Kortes, STMD Director of Technology Demonstration Missions (TDM), introduced Ms. Tawnya Laughinghouse, a program manager at Marshall, and Mr. Jason Adam, who works on CFM at Marshall. CFM is its own portfolio within TDM and is relied upon by NTP, in-situ resource utilization (ISRU), and other systems and technologies. Ms. Laughinghouse began the presentation by discussing the program overall. TDM executes a broad range of system-level demonstrations in space. These tend to be high risk, at TRLs 5-7, and the goal is to learn from these tests in order to move the projects forward.

In 2022, TDM had 13 projects with 27 partners in 22 states; Ms. Laughinghouse reviewed some of the highlights. LCRD will inform future missions using optical communications and there are plans to have it on ISS. Satellite servicing and solar propulsion projects have gone through Critical Design Review (CDR). CFM will be important for solar electric propulsion (SEP). MOXIE has extracted oxygen from the Martian atmosphere. The program also delivered DSOC flight hardware. The program is reviewing the Psyche report, and TDM will hold a forum in conjunction with the annual review in March to discuss the report with the community. Finally, LOFTID was delivered ahead of time and successfully launched.

LOFTID is an Entry, Descent, Landing (EDL) technology that extends NASA's inflatable decelerator tradition. It is stowable and deployable. The test worked well, showing that this technology can survive the searing heat of reentry. It was the largest blunt body shield to come through the atmosphere to date. The scalable design, developed in partnership with industry and multiple centers, has many potential applications. A graphic depicted the mission timeline, which Ms. Laughinghouse described. There was a bit of damage to the nose cone on splashdown. LOFTID carried two data recorders, one of which was designed to be ejected; this worked as planned, with recovery of the softball-sized device. It came in at 8.1 km/second.

Dr. Kramer-Bottiglio asked about the pressure differential for landing. Ms. Laughinghouse explained that it was fairly stable. Mr. Rush asked about the release altitude; it was ejected at 50,000 feet. Ms. Laughinghouse said that LOFTID met all of its Level 1 mission requirements. NASA is now examining the flight hardware and going through the results. The data recorders are giving engineers a map of how it operated. It appears that the back side was successfully protected. Dr. Weber asked about the margin for protection. Ms. Laughinghouse said that that is something they hope to learn in the debrief.

LOFTID was dedicated to the memory of ULA engineer Bernard Kutter, who was key to the technology development. The recovery team had to adapt to COVID-19 but still delivered early. TDM took over LOFTID in 2018, at which point it had had 10 years of investment.

Mr. Adam then discussed CFM, which is an umbrella project addressing liquids in space, including their storage and transfer. It involves refrigeration, pumps, and chemistry, much of which is enabling and critical. The program picks up elements that are at TRL 4 or 5 and moves them to TRL 7 so that they can be addressed by others. While some CFM work takes place on the ground, there are physics issues necessitating testing in space. The program is organized around technologies, subsystems, demonstrations, and modeling. Mr. Adam described some of the investments. In order for a mission to return from Mars, NASA will need to get 15 to 20 times the lift currently possible. Fluid dynamics will be important for NTP, which requires two-stage cooling. The portfolio also includes liquification and storage. NASA is the primary home for thermal modeling expertise, and the program is constantly seeking flight opportunities on which to validate models. To address limitations, leveraging is crucial.

A map showed the breadth of the nation's work on this complex project. Almost every SME in the agency is involved in it. Contracts address liquefaction and flight demonstrations. Tipping Point awards require corporate contributions reflecting the size of the company. There are some industry activities driven by the direction of the market. As appropriate flights materialize, the program tries to engage.

Of the four contracts awarded in 2020-21, all have moved or are about to move from design to fabrication. All are fixed price contracts with a similar structure, and launches are planned from 2023-25. Mr. Adam reviewed each of the four contracts. All of them include a mechanism for the company to leverage government expertise or facilities. NASA wants to move this to vendors while also protecting intellectual property as needed. One contract, with ULA, involves autogenous pressurization that is of interest to NASA. A summary chart showed what is being done in each contract.

Another graphic illustrated the uncertainties of the longer-term objectives and the intricacies of the plans. A larger NTP system will require CFM, and there will have to be an intermediate stage. Demonstration of a large CFM mission is already in the concept phase. The next layer of detail has been mapped out by activities and current feasibility. Some demonstrations are planned to push the state of the art. Operational considerations were not shown, but there is good coverage leading to a Mars mission. The Tipping Point efforts are not sufficient to get NASA to Mars; there will have to be a large demonstration, probably in the early 2030s, to test storage and transfer of a scalable quantity of liquid hydrogen.

Mr. Johns said that TI&E has been looking for a gaps chart, and asked if there is one mapping gaps to future missions. Mr. Adam said that there is one, at least two layers deeper with cross-cutting considerations, and he can provide it. There is a chart mapped to concept studies as well. It is a continual process and shows good alignment with Tipping Point investment areas. The project has met with Mars teams to ensure that all mission demands are lined up.

Dr. Mitchell Walker asked about the amount of electrical power required. Mr. Adam did not remember, but it is tracked, and the large CFM demonstration can be flown on a commercial bus with the hydrogen. Transfer from one vehicle to another is a different issue and needs to be worked through. Ms. Kortes noted that LOFTID went to 654km, about 400 miles.

Office of the Chief Engineer (OCE) Update

Mr. Joseph Pellicciotti, NASA Deputy Chief Engineer, noted that he would become the Acting Chief Engineer the next Monday, after the retirement of Mr. Ralph Roe. Despite the pandemic and supply chain issues, NASA accomplished a lot in Fiscal Year 2022 (FY22), and the OCE was involved throughout. Mr. Pellicciotti reviewed these by mission directorate, making special note of Artemis and JWST. Within STMD, there were the LCRD, DSOC, CAPSTONE, and MOXIE. The NASA Engineering and Safety Center (NESC) started 80 new technical activities in FY22, and more work is expected in FY23.

OCE is now preparing for FY23, and will analyze the many lessons learned from JWST, Artemis, LOFTID, and other activities. OCE will work with STMD on SEP, Thruster Advancement for Low-Temperature Operation in Space (TALOS), PRIME-1 launch and lunar demonstration, and Cooperative Autonomous Distributed Robotic Explorers (CADRE) delivery of flight hardware for lunar demonstration.

NASA has moved the standards function from OCE to the executive suite, but everything else remains the same. The Office will continue to be active in assessing missions.

Mr. Johns asked about the Psyche report in terms of how it affects OCE and what might be learned from it. Mr. Pellicciotti said that one important thing coming from the report was that the roles of systems and chief engineers need clarification. This was a major finding from the report. Psyche did not have a chief engineer, and this gap appeared to have an impact. Some projects have both systems engineers and a chief engineer, but when it is just one or the other, the responsibilities of both roles still need to be filled. NASA needs to ensure proper training of systems engineers and to look at how that can be done better. A piece of that is integrating and training early career individuals while retaining good, veteran employees. Psyche had a number of issues, but he gathered that the issue was essentially a proximate cause of software incompatibility. Otherwise, it has been a banner year in spite of Covid and other issues.

Early Career Initiative Researcher Presentations
Mr. Green said that on the previous day's tour, TI&E members met four researchers from the Early Career Initiative (ECI). Two were to give presentations at the meeting.

Lunar Thermal Regulation for Mission Sustainability (TheRMiS)
Mr. Will Johnson described his project, which focuses on systems needed for humans to survive extreme lunar environments. His award began just as the covid shutdowns started, so NASA gave him an extension to accommodate for the need to pivot. He noted his team members, most of whom were also early career individuals. The team had a strong partnership with a company called Astrobotic, which was already doing work in this area. TheRMIS was only able to do one of the two planned flight demonstrations, however. Part of what he learned from the ECI experience had to do with activity timelines. Dr. Kramer-Bottiglio asked if partnership is a requirement. Mr. Johnson explained that 25 to 45 percent of the funding is supposed to go to an external partner, which took a while to identify and which he did during the proposal stage.

The project built on the assumption that small landers will be necessary for lunar activities. With the extremes of temperature on the Moon's surface, robotic landers will face challenges, and TheRMIS sought to address those issues by investigating alternatives. The study had four aspects: nighttime survival, matrix of candidate technologies, sensitivity studies, and validation of the matrix. Validation was the most important of these.

TheRMIS collaborated with JSC on integration and testing (I&T) of the Volatiles Investigating Polar Exploration Rover (VIPER). This involved a number of thermal-vacuum (TVAC) tests, including a loop heat pipe (LHP) in lunar gravity orientation. The project moved on to testing an additively manufactured LHP, which remains at a low TRL. A hybrid thermal control system was developed as a joint project with the Marshall Spacecraft and Vehicle Systems Department, using both an active pumped fluid loop and a passive LHP to replace the external loop.

Mr. Johnson described the flight hardware, which required that he leave his comfort zone and learn about pipe testing. LHP can shut off on its own, and a hybrid wick can balance that out. The Variable Conductance Heat Pipe (VCHP) has a smaller line that prevents unwanted diffusion of fluids. More hardware is being tested, including different types of heat pipes. Marshall is building lab capabilities to make it easier to do this work in the future, raise the TRL, and get this technology infused.

Mr. Johnson listed the knowledge transfer activities in which the team participated. There were problems due to COVID-19 that led to greater reliance on modeling, and supply chain issues required further flexibility. He learned that asking questions is crucial, and people want to help. Contracting and procurement were challenging, with lots of delays and people to talk with, which emphasizes the need to communicate well. Frontline managers were not aware of the impact the award would have on his workload, which also called for strong communication.

The program did have a positive impact on his career, teaching him how to manage projects and be a good technologist and PI. The perspective, skills, and partnerships are invaluable. A lot of new PIs do not know where to start, which speaks to the need for additional training and a possible on-ramp period for training and planning. Early career workers could also use help in knowing how to move forward once a project is over. While his managers had to deal with his absence from normal responsibilities, they now recognize his growth and give him more responsibilities. Dr. LaPointe noted that some ECI award winners have moved on to other work. Dr. Kathleen Howe asked if branches automatically look at the progress these ECI awardees have made. Mr. Johnson thought they were more interested in what was happening at the moment, but they did see the skills he gained.

Mr. Reuter added that there might not be immediate opportunities for infusion because the structure does not exist, but these projects have potential for the future. STMD is trying to recognize the value, but budgets do not support all of this work going forward. Dr. Michael Zanetti said that he had a lot of the same issues in his ECI project. There has been informal networking among the ECI awardees.

Kinematic Navigation and Cartography Knapsack (KNaCK)
Dr. Zanetti then described KNaCK. He is a lunar and planetary geologist, and he wanted to make a tool for that discipline, especially for lunar and Martian exploration. The commercial partner on his project was Torch Technologies. He reviewed the team, which included university and vendor participants, many of whom were also new to the field. There was no guideline on how to assemble the teams. Most branch managers supported this and contributed personnel.

There will be challenges in mapping at the lunar South Pole, where there will be no GPS or illumination. The shadows throw off the perspective, and there is the case of direct sun and the complete washout. Light Detection and Ranging (LiDAR) sensing is a solution that removes solar illumination as a befuddler. Dr. Zanetti ran a video of a drone flight, showing how velocity-sensing Frequency Modulated Continuous Wave (FMCW) LiDAR can detect the range and Doppler-shift. In the model, the colors help measure how fast these elements are moving. If the scene is static, it provides information about the user's own position. The project went beyond KNACK's three proposed goals, to begin environmental testing. The team built two and a half iterations of a backpack and four modular headstocks, and also did successful mapping. Through iterations, the portable KNaCK device – the backpack – came down to a manageable 5 pounds. As spinoffs, the team developed a small fleet of little rovers that can work together in a swarm. A goal is to have astronauts and rovers working together, even at night.

A graphic showed the 3D mapping of the path Dr. Zanetti took through the Marshall campus while wearing the backpack. Additional examples provided a finer level of detail, showing multiple use cases in many fields of study. In another test, the team collected 36 linear miles of data at KSC. Mr. Johns asked about the amount of data processing needed. Dr. Zanetti replied that it is a lot, but the system is almost to the point where the results can be available in real time. Storage is intense, but processing is less so.

A number of scientists met to discuss the Solar System Exploration Research Virtual Institute (SSERVI) use of KNaCK, determining that it could help them place where their measurements were made. After the project ended, the KNaCK team was invited to work with the NASA Joint Extravehicular Activities (EVA) Test Team-3 (JETT-3) in a nighttime mapping and navigation exercise. It was determined that KNaCK diminishes errors even on a long traverse. KNaCK did testing in Iceland with the Rover Aerial Vehicle Exploration Network (RAVEN) as well, which was a good lunar analog. A remaining question is the amount of precision that will be needed. At this point, the technology is good within 2 meters. Another aspect of the test had remote piloting of the Iceland rovers by team members working at Marshall. Additional tests took KNaCK into an Alabama quarry, inside a building, and to a field with terrain like lunar regolith. Next steps focus on keeping the work going, probably in the areas of miniaturization, system optimization, and additional uses. Some of the lessons learned were the same as for Mr. Johnson's project. Procurement is not simple, and project management can be problematic. Mentorship was key.

Dr. Howell noted that astronauts need to see what is happening at their feet. Dr. Zanetti agreed, noting that space suits do not even allow them to crane their heads forward, so tripping hazards remain on the list of items to address. Dr. Kramer Bottiglio asked about rovers working together. Dr. Zanetti said that the testing was only for a backpack and a rover, not multiple rovers. Dr. Kramer Bottiglio spoke to the great potential in having multiple units deployed simultaneously, and asked about the feasibility of real-time data processing under those circumstances. Dr. Zanetti said that real-time communications among devices would be a logistical challenge. However, having such data available on a map within a couple of hours is a possibility. There is a one-to-one correlation between time the device is in use and time needed to process. A single rover might be able to produce a good hazard map. Simultaneous deployment of multiple systems is a goal, however. Dr. Kramer Bottiglio asked about the amount of computing power this scenario might require. Dr. Zanetti said that the project is not currently working with anything other than space-capable hardware. Also, the active source imaging technique has broad applicability beyond just enabling astronauts to see into shadows.

Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT) Update

Dr. Raymond Clinton described the MMPACT activities for lunar landing and operations. The team determined that there is no need to have a monolithic slab for a landing pad, instead relying on optimization of lunar materials. A lighter crane arm lends itself to dual use technologies as well. The goal is to do construction on the Moon to meet human needs, using lunar materials to the extent possible. This requires validation on Earth where feasible. The plan is to incorporate instrumentation and evaluate materials prior to lunar use. A video illustrated the progression from lab to field to the Moon and Mars, using 3D printing. The industry partner, ICON, had been a finalist in a NASA Centennial Challenge and moved on to other things. Both NASA and DOD are interested in partnering with ICON. Some of the work involved leveraging SBIR matching funds.

Once on the Moon, the plan is to begin with horizontal plane infrastructure, then work toward more vertical structures. One issue is that the lunar surface presents astronauts with even more hazards than they would encounter on Mars. The harsh environment includes radiation, meteoroids, dust, extreme temperatures, and seismic activity. At the same time, transporting materials via rocket quickly becomes unrealistic from a funding standpoint, which speaks to the need to use the in-situ resources. Dr. Clinton showed a roadmap for lunar construction capability development, involving four phases, two demonstration flights, and two qualification missions. The phases and missions are not in complete alignment. Construction concepts even consider how to create furniture for the astronauts.

The concept for the first demonstration mission addresses dust avoidance and the need to exit the lander. Regolith will need to be tested before it can be used. The mission will do autonomous operations and gather data to validate models. It should be able to identify gaps and progress the TRLs. SBIR recently gave another award to ICON for this project, through delivery of flight hardware and with the option to operate. The demonstration timeline and milestones will address a number of NASA goals and initiatives.

The Crew Health and Performance Exploration Analog (CHAPEA) program tests an Earth-based mockup habitat ICON created to understand what astronauts will need for life on Mars. Testing will involve having several crews live there and will help determine what the astronauts will really need. Dr. Clinton reviewed some of the project accomplishments thus far. The team had to develop its own regolith analog. MMPPACT worked with other NASA partners, government agencies, and industry. Dr. Clinton made special note of MMPACT's Cooperative Agreement (CAN) with Drake State Community and Technical College, a

Minority Serving Institution (MSI) based in Alabama. The Drake template is being taken to Sinte Gleska University, a two-year college that serves the Brule Lakota nation in South Dakota. The Drake program developed a curriculum, won a subsequent award, and has leveraged its effort to train high school students and teachers.

In his summary, Dr. Clinton noted that the goal is to bring together the various elements so that the commercial partners can develop a viable lunar economy by the 2030s. For that to happen, the demonstration missions will be necessary.

Dr. Weber asked for more about ICON. Dr. Clinton explained that the CEO brought his kids to Space Camp and also showed Marshall engineers what ICON had done. MMPACT was impressed by their capabilities. The company was engaged in constructing housing for the homeless in Austin, working with the Texas National Guard, among others. At that point, the company had about 20 employees. Although the pandemic affected the project, by late 2022, they had grown to a staff of 500. ICON has five machines constructing 3D printed houses for the needy, which was the original purpose. They use a proprietary concrete mixture.

Mr. Johns asked if NASA Kennedy was engaged in the landing pad project. Dr. Clinton said that it was, bringing expertise in site preparation and excavation. To print furniture in free space, ICON uses a technology with beads of ¼-inch or less. The laser system is looking at 2.5 mm diameter. Dr. Kramer-Bottiglio said that a group at NASA's Ames Research Center in Silicon Valley, California has come up with an optimized, modular structure and she wondered if there could be synergy. Dr. Clinton said he has seen the video of robots placing and reconfiguring structures, and he wonders about the origin of the structures and how the pieces will get to the Moon.

Variable density and geometry of a landing pad were among the lessons learned from an advanced concepts study. The representative landing pad structure initially targeted did not have sufficient power for continuous operations. This led to questions about what the landing pads really need, and the realization that a monolithic slab is not necessary. He was to get the first output of the JPL thermal structural analysis the following day. MMPACT and ICON attend the Lunar Science Interest Group meetings.

Discussion, Findings, and Recommendations

Mr. Johns asked the TI&E members for their thoughts so that he and Mr. Green could develop a presentation for the January NAC meeting.

Dr. Kramer-Bottiglio said that what resonated most was the ECI projects and the opportunities to link with other PIs. It would be nice to see this through as an entry point to NASA. She is familiar with the lunar infrastructure projects and would like to see linkages and synergy instead of everything seeming so disparate.

Dr. Gazarik referred to previous discussions about Space Tech and the various launch platforms, which he thought made for a great story. He wondered if there might be a connection with the National Reconnaissance Organization (NRO) and others who might coordinate. He also wanted to help the NASA workforce.

Dr. Bradford Tousley praised the presentations. As attrition has become common, he worries that NASA might lack the flexibility needed to address it. On the other hand, the infrastructure work is great. It can take 50 years to make a big advance like the recently announced DOE breakthrough on fusion. He thought the NEP and NTP work was great, but again wanted to ensure synergy with the rest of the federal government. The costs for launch are steadily going down, which should be a leverage point.

Mr. Rush agreed that the presentations were strong. He would like to see where LOFTID is going next. ECI is an awesome program and STMD seems to be a focal point for some of NASA's workforce development. The on-ramp training is a good idea, so that people are casting about less. Mr. Reuter said that Technology Transfer covers some of that. STMD could emulate the PI Bootcamp run out of SMD. Mr. Rush liked that idea and cited the need to help people understand the industry focus and how it relates to NASA. The story of MMPACT and ICON was a great example of leverage. He worries about depth versus breadth on NEP and NTP.

Dr. Walker would like to see the retention effort focus on stories rather than moments, in order to have more impact and help workers envision their trajectories. He was also interested in the work being done to understand the on-orbit environment at a deeper level. The NEP and NTP work presents a range of problems but is manageable and will lead to terrestrial applications; he liked where this was going. Dr. Howell said the workforce issue also reflects the anticipated drop-off of the overall population, which will affect every sector. It speaks to the need to think long-term. On the nuclear side, NEP is part of a longer vision, which still needs advocacy. She liked the CFM gap chart and would like to see a pathway for ECI infusion. That seems to be missing.

Dr. Weber said that while what they saw was amazing, she kept thinking about the NAC. She wondered if there should be an update on what is going on with STMD, including a look at successes and how it all affects Artemis and enables current projects. This would show how STMD has been integral to NASA success. A budget chart would be helpful. TI&E previously showed how STMD investments have paid off, using impact stories. Mr. Green said that there is always a budget chart, and Mr. Reuter pointed out that the bulk of the budget is directed. Dr. Weber said that while NTP work is Congressionally directed, STMD is filling in the gaps on NEP. Mr. Reuter explained that Congress often directs STMD to do what NASA says it wants to do, but the balance is different. The goal is to put together a demonstration list, but he needs to work forward on that. NEP does not necessarily require CFM for the Moon but would need it for Mars, possibly with methane instead of hydrogen.

Mr. Johns said that he would like to have a slide on the 2022 in review. He added that what TI&E calls observations, the rest of the NAC calls findings, even statements like "doing a great job." He wondered if there might be a recommendation on SBIR and the tools to set it. It is a large portfolio. Regarding ECI, he also thought about having a bootcamp, preparing for successes, and transition to other funding mechanisms. Mr. Reuter noted that having a senior person as a mentor is a requirement. Dr. Weber said that the bootcamp needs to begin before the funding starts. Dr. LaPointe agreed, stating that this is something the program has considered based on feedback from ECI participants. The FY23 budget cannot accommodate the additional time to ramp up, but that will be requested for FY24. He would also like to expand on a training office program done last year.

Mr. Johns suggested that a future meeting have an NEP roadmap, like TI&E saw for NTP some years ago. Other agencies are looking at this. He would also like to look at the Psyche report. Dr. Weber asked for a CAPSTONE update, which Mr. Green agreed to for the next meeting. There were issues in Congress with SBIR/STTR, and there will be an update on them as well, including data on SBIR successes. Dr. Weber wanted to know if STMD is working on anything that is on the critical path for Artemis 3, or anything worrisome. Mr. Reuter said that there is not much on the Artemis 3 critical path beyond propulsion and some enhancements.

Dr. Gazarik said he would like to hear about ground systems, which is a topic of community interest. He was also interested in partnerships with other agencies. Mr. Reuter said that the partnerships will reflect the budget. There are some technologies on the first few landers.

Mr. Green said that the spring meeting is likely to be in Washington. That will be a good time to discuss the budget. He then thanked everyone.

Adjournment
The meeting was adjourned at 5:29 p.m.

Appendix A

Agenda

December 15 – FACA Public Meeting

8:30 a.m.	Overview of Agenda/Logistics Mr. Mike Green, Executive Secretary
8:35 a.m.	Opening Remarks Mr. Michael Johns, Chair
8:40 a.m.	Welcome to NASA's Marshall Space Flight Center Ms. Jody Singer, Director, NASA Marshall
9:00 a.m.	Space Technology Mission Directorate (STMD) Update Mr. James Reuter, Associate Administrator, STMD
10:00 a.m.	NASA Nuclear Systems Update Dr. Anthony Calomino, Space Nuclear Technologies Lead, STMD Mr. Jason Turpin, Project Manager, Space Nuclear Propulsion, Marshall
11:00 a.m.	Break
11:10 a.m.	Technology Demonstration Missions: Cryogenic Fluid Management and Low-Earth Orbit Flight Test of an Inflatable Decelerator Updates Ms. Trudy Kortes, Director of Technology Demonstrations, STMD Ms. Tawnya Laughinghouse, Program Manager, TDM Program, Marshall Mr. Jason Adam, CFM project, Marshall
12:10 p.m.	Lunch
1:00 p.m.	Office of the Chief Engineer (OCE) Update Mr. Joe Pellicciotti, NASA Deputy Chief Engineer
1:30 p.m.	Early Career Initiative Researcher Presentations Lunar Thermal Regulation for Mission Sustainability (TheRMiS), Will Johnson, Marshall Kinematic Navigation and Cartography Knapsack (KNaCK), Michael Zanetti, Marshall
2:15 p.m.	Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT) Update Dr. Raymond Clinton, MMPACT Principal Investigator, Marshall
3:15 p.m.	Break

3:30 p.m.	Discussion, Findings, and Recommendations
4:45 p.m.	Adjournment

APPENDIX B

Committee Membership

Mr. Michael Johns, Kratos SRE, *Chair*
Mr. G. Michael Green, *Executive Secretary*
Ms. Lisa Callahan, Lockheed Martin Space
Dr. Michael Gazarik, Ball Aerospace
Dr. Kathleen C. Howell, Purdue University
Dr. Rebecca Kramer Bottiglio, Yale University
Mr. Andrew Rush, Redwire
Dr. Bradford Tousley, Raytheon Technologies
Dr. Mitchell Walker, Georgia Institute of Technology
Dr. Mary Ellen Weber, Stellar Strategies, LLC

APPENDIX C

Presentations

1) Welcome to NASA's Marshall Space Flight Center [Singer]
2) STMD Update [Reuter]
3) NASA Nuclear Systems Update [Calomino, Turpin]
4) Technology Demonstration Missions: Cryogenic Fluid Management and Low-Earth Orbit Flight Test of an Inflatable Decelerator Updates [Kortes, Laughinghouse, Adam]
5) Office of the Chief Engineer Update [Pellicciotti]
6) Lunar Thermal Regulation for Mission Sustainability [Johnson]
7) Kinematic Navigation and Cartography Knapsack [Zanetti]
8) Moon-to-Mars Planetary Autonomous Construction Technology [Clinton]