National Aeronautics and Space Administration

Technology, Innovation & Engineering Committee of the NASA Advisory Council

NASA Headquarters
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Meeting Minutes

G. Michael Green, Executive Secretary **Dr. Bill Ballhaus Chair**

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Meeting Report prepared by
Elizabeth Sheley

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Welcome and Overview of Agenda/Logistics
Mr. G. Michael Green, Executive Secretary of the NASA Advisory Council (NAC) Technology, Innovation, and Engineering (TI&E) Committee, welcomed the members. The Committee faced a number of changes. Mr. Gordon Eichhorst completed his term as a member, and this was the last meeting for Dr. William Ballhaus, TI&E Chair, who was unable to attend in person. Mr. James Free had joined the Committee and would take over as Chair in the new year. Dr. Matt Mountain was serving as co-chair for this meeting and, along with Dr. Ballhaus participating remotely, would represent TI&E at the NAC meeting the following week.

Opening Remarks
Dr. Ballhaus, participating remotely, thanked Dr. Mountain and the other members, then welcomed Mr. Free and wished him success. He asked that they think about the message they wanted to leave with NASA Administrator James Bridenstine.

Space Technology Mission Directorate (STMD) Update and Discussion
Mr. James Reuter, Acting Associate Administrator for NASA's Space Technology Mission Directorate (STMD), explained that he would be in and out of the meeting due to other commitments. TI&E was to have presentations on the Lunar Gateway, cryogenic fluid management (CFM), in-situ resource utilization (ISRU), and the Computational Design Space Technology Research Institute.

NASA was operating under a Congressional Resolution (CR) until December 21, and there was a serious threat of a furlough after that. Many Federal agencies already had their appropriations for Fiscal Year 2019 (FY19), but NASA did not. A full-year CR was STMD's most challenging scenario, followed by the House mark-up. Under the CR, the operating budget was close to the FY18 amount, $761 million. The FY19 President's Budget Request (PBR) was for $860 million without the Human Research Program (HRP). The Restore-L program has its own funding. The net impact from a full-year CR is $150 million below the plan. The Senate mark-up was the most favorable. Both houses of Congress include direction in their appropriations bills; some of that is law and the rest is report language, which involves the operating plan and has some negotiating room. The Restore-L project mark-up was $180 million in the Senate and $130 million in the House. For another program, Nuclear Thermal Propulsion (NTP), the House draft directs $150 million, with the Senate at $175 million. STMD has met that through risk reduction activities, part of a successful 4-year plan for which the Directorate is in the final year. Cryogenics in space has been counted as NTP and supports the agency's Lunar Exploration Campaign directly. There are several other Congressional directions that are reasonably consistent with what STMD does already, and those are manageable.

NASA submitted its FY20 budget proposal to the Office of Management and Budget (OMB) in September. This is still in discussion and will be embargoed until February. Meanwhile, the FY21 budget process has begun. STMD's approach gives priority to the Lunar Exploration Campaign, in the context of eventual human exploration of Mars. STMD keeps a portion of the portfolio dedicated to Mars-related activities and is preparing specific areas to address.

The next Tipping Point call will be released in January. After seeking feedback, the program learned that proposers liked the two-step process and the more open topics, but would prefer a bit more guidance. The guidance system transfer concept came out, but with NASA under a CR, it is hard to shift in that scenario. Mr. Reuter described how NASA determined which projects to have in STMD and which belong in the Human Exploration and Operations Mission Directorate (HEOMD). HEOMD took engineering and projects for which it has a history, while STMD has technology development and engineering projects that have been in its portfolio and are well along the way. For example, STMD has all in-space manufacturing and ISRU, as well as Mars 2020 instruments. Items supporting the Gateway or lunar landers stay with HEOMD, as do technology development projects nearing completion or requiring unique skills.

Dr. Ballhaus noted that in March, TI&E was concerned about whether STMD might be restructured. In the Committee's report to the NAC, they pointed out that NASA's major missions have been enabled by technology development over a number of years, even decades. Experience shows that housing the early Technology Readiness Level (TRL) investments in the other mission directorates leads to unfortunate funding reductions. In addition, the other mission directorates did not sustain interactions with universities on technology development, which is essential. STMD was created to reverse these outcomes. NASA now has impressive university relationships in the technology area. While TI&E understands that the Science Mission Directorate (SMD) will fund its own technologies, STMD has done some of the early work.

Mr. Reuter said that SMD will have to do more. HEOMD is focusing the Advanced Exploration Systems (AES) activities on the Gateway and human-class landers, as well as habitation and life support. The Gateway technologies will be derivatives of those demonstrated on the International Space Station (ISS). STMD will work on the lower TRLs and some life support. Retention of STMD as a mission directorate is still an active topic. Mr. Bridenstine is convinced of the need to maintain a protected space technology budget across the TRL spectrum, with a strong university component. The funds would be fenced off, but the structure may change. STMD suggested that an early stage innovation budget should always be 8 percent, whereas it had been 7 percent. The concern becomes how exposed the budget would be. Former STMD Associate Administrator Steve Jurczyk is now NASA Associate Administrator, which helps.

Mr. Michael Johns pointed out that the House had strong language rejecting the reorganization. Mr. Reuter confirmed that, adding that the Senate language was even stronger. Appropriations have to reflect a change, but some internal shifts might occur. Dr. Ballhaus suggested that it might be a good time to repeat some of the points from the March presentation. Mr. Free asked how Mr. Reuter planned to protect the budget for the Mars Oxygen ISRU Experiment (MOXIE) and other instruments in Integration and Testing (I&T). Mr. Reuter replied that MOXIE is a clear case of what STMD should be doing, and it should be delivered by March.

Cryogenic Fluid Management Update

Ms. Dayna Ise, Acting Technology Demonstration Mission Program Executive, said that STMD is looking at how CFM plays into Agency goals. She presented examples of CFM applications that support NASA's Low-Earth Orbit (LEO), cislunar, and Mars exploration efforts. A bar chart illustrated the development needs according to mission duration. Generally, the longer the mission, the less development activity there has been. Ms. Ise presented a list of the 25 technologies that must be advanced to meet NASA goals, in order of TRL. She pointed out that TRL6 is the typical requirement, even on some flight demonstrations. Dr. Mountain suggested that she find a way to combine the two charts, which Ms. Ise said had been done for specific technologies on specific missions.

Dr. Ballhaus explained that when asked how their technology development would change if they could only use commercial sources, HEOMD indicated that CFM would need to be developed to reduce boil-off. Ms. Ise explained that the technologists had a roadmap that was more focused on Mars and methane. They have been updating that, and she was showing things that had not changed. Dr. Ballhaus said that until NASA proceeds with some of these technology developments, the Agency was trading a day of work for a day of delay. It is important to show the mission pull as an urgency argument. Presumably, the Gateway will provide some of that. Options for further in the future do not have the same urgency. Mr. Free noted that gravity dependency could vary by destination. Ms. Ise agreed, stating that that is part of the discussion. Regarding commonality for surface systems on the Moon and on Mars, she explained that the program is always supposed to keep Mars in mind during the lunar projects, with traceability. Dr. Mountain said that the job of technology is to ensure commonality.

Ms. Ise listed current activities, many of which are funded through the e-cryo program. For the Robotic Refueling Mission 3 (RRM3), an exterior demonstration payload on ISS, the cryogen is methane. She described some of the FY19 work on cryocoolers and discussed the four CFM Tipping Point awards, explaining what the tests will involve. About five or six CFM items still need coverage. STMD hopes to address these through additional Tipping Point and Announcement of Collaborative Opportunity (ACO) awards. There are some lunar opportunities, and the program has discussed small development projects on SMD's Commercial Lunar Payload Services (CLPS) landers and larger projects. There have also been discussions of a large, multi-technology lunar demonstration.

STMD is working with subject matter experts and industry to address gaps in the roadmap. Dr. Kathleen Howell asked about mapping gaps against mission duration. Mr. Wesley Johnson said that critical technologies are deemed urgent, but the para to ortho technology does not seem like it will fall into that category. Ms. Ise explained that there are priorities with industry interest. If something has neither industry interest nor current mission pull, it is not considered urgent. Dr. Mary Ellen Weber asked that the gaps be presented with the technology they enabled and their durations.

Mr. Free asked about testing the Structural Heat Intercept Insulation Vibration Evaluation Rig (SHIIVER) technologies. Ms. Ise explained that that is specific to an industry test. Dr. Prasun Desai added that if industry can use the SHIIVER technology, they can access Agency assets. When Mr. Free asked about international participation, Mr. Michael Meyers answered that there has been some good collaboration with the Japanese Space Agency (JAXA), and Mr. Johnson noted that the German Aerospace Center (DLR) has been working with NASA on Zero Boil-Off Technology (ZBOT).

Ms. Ise listed key technology challenges for which CFM technology development is necessary, including the Gateway, lunar surface operations, and rapid transit to Mars. The enabling technologies map back to the list.

In-Situ Resource Utilization Planning and Update

Mr. Gerald Sanders, Systems Capability Leadership Team Lead at Johnson Space Center (JSC), coordinates ISRU across NASA. ISRU encompasses hardware or operations that harness or use in-situ resources to create products and services for robotic and human exploration. The six categories of ISRU work tap into traditional and non-traditional resources. ISRU does not exist on its own, so it must connect to users of its products. Across many steps and interfaces, ISRU enables space exploration that makes materials and supplies instead of bringing items that are needed. It increases mission performance and sustainability, decreases lifecycle costs, reduces mission and crew risk, and amplifies science. It must be considered at the start of a mission in order to maximize benefits and cost reductions.

Water is the major resource that is discussed most, and the ISRU team looks at the destinations and commonalities. Oxygen is another frequent ISRU topic. Mr. Sanders described the moon, Mars, asteroids, and utilization in terms of water oxygen, carbon, and metal availability. The team looks at the implications of each environment. Mr. Sanders then presented the ISRU strategic vector by current technology and feasibility, near-term development and demonstrations, and mission utilization goals. A lot of work has been done on ISRU over the years, and the data on lunar and Martian resources are substantial. There are limits, however, especially when it comes to the various forms of water. The current focus is on obtaining more prospecting data.

Mr. Free asked about power systems, noting the challenge presented by nuclear. He asked how that was laid out against development work. Mr. Sanders said that the efforts were aligned, as with solar. The elements such as weight, processors, etc., are part of the calculations. He noted that power systems are often shared, which brings down costs. ISRU operates before the crew shows up, in order to power the habitat. Dr. Desai said that cost savings come with multiple visits. Mr. Free recommended stating up front that the effort is integrated with the power system, and denoting the increment.

Mr. Sanders compared mission consumables, oxygen, water, and volatiles from regolith, and described proposals to extract oxygen from lunar regolith. Two processes have been developed to TRL4-5, and the basic techniques have been demonstrated. He also presented the technologies advanced in the 2000s, with their TRLs. A concept of operation is the full ISRU O_2 plant. While there is interest in the lunar polar resources, a challenge is how to set up mining at a permanently shadowed crater.

Not all of the challenges are technical. There are concerns about resources, operations, and integration. In addition, planetary protection is a concern and a challenge. NASA does not want to kill a life form in the course of exploration, for example. Overcoming these challenges requires a multi-destination approach consisting of resource prospecting, process testing, and product utilization. Some of the solutions might be counterintuitive. For example, the logistics and economics of mining for water on Mars are such that ice deposits would require more work than would the less-rich surface pebbles. The development strategy is to prospect for resources, extract and process them, and produce what is needed from extraterrestrial materials. Mr. Sanders described the enabling capabilities, development approach, and path to operational ISRU. NASA is reaching out to industry and universities. ISRU must be demonstrated before it can become mission-critical.

Dr. Weber noted that water electrolysis has been proven. She asked about the challenges on the Moon. Mr. Sanders said that there were two questions here. First, how clean must the water be? And which electrolysis process should be used? Each has large-scale architectural, mass, and complexity implications. He described biological processing technology development activities, along with civil engineering and in-situ construction activities. The big one is NASA's 3D-Printed Habitat Challenge. Lunar ISRU research and missions are underway and under development. NASA leads in most areas and is leveraging both internally and externally. The Agency is looking at investments with mining companies, for example, as well as with SpaceX and Blue Origin. ISRU has strong capabilities related to space commercialization. ISRU is not seeking efficiency first but, rather, aims to provide benefits that can be improved.

Dr. Ballhaus said that technology investments create a lot of options, most of which will never be exercised. This calls for a good analysis capability to determine which low TRL technologies should be advanced through the "valley of death" to applications. Mr. Sanders agreed, giving the example of a disconnect on the Constellation water electrolysis system, where the various systems sought optimization of their areas but missed seeing the integrated whole.

Mr. Free said there ought to be a project plan or guide with timelines and dates. Mr. Sanders explained that the program was in a difficult position at the moment. The way forward is clearer for Mars. For the Moon, they are developing the architecture and have limitations. They have determined the amount of oxygen needed by the system on the Moon and are about to have a demonstration run at NASA's Glenn Research Center (GRC). He will know soon. Mr. Free added that they will need to analyze the funding and the focus, and he wondered about the roadmap. Dr. Desai explained that having all the activity in one place will help in working the budget. Congressional direction is a source of inflexibility, though. Dr. Ballhaus said that the Mars approach was so far out that there was no project plan or pull to use as a basis for an urgency argument.

Ultra-Strong Composites by Computational Design Space Technology Research Institute Update

Dr. Mia Siochi of NASA Langley Research Center (LRC) described this materials development project, which is being done through a Space Technology Research Institute (STRI). The STRI program capitalizes on universities being able to cross disciplines in order to understand the needs and the larger materials ecosystem. The Institute has a technology advisory board made up of industry members who provide guidance as potential users. STMD did some internal work in this area under the Game Changing Technologies effort, and so had some understanding of the goals and what might be possible. This is a virtual institute with 11 participating universities, led by Michigan Tech. Lightweight structures are critical to the space exploration enterprise. The cost of launch, for example, reflects the mass ratio, and destination is a factor. Mars exploration could cost $1 million per pound, for example.

Dr. Siochi then graphed the Carbon Nanotube (CNT) on the Gartner Hype Cycle, noting the greatly inflated expectations for CNT. The technology is now in the "trough of disillusionment" despite potential for mechanical enhancement. Mapped against the hype cycle, the publication rate showed about 200,000 papers on CNT, mostly the powders. It is now clear that the powders will not provide the desired properties, and the research focus is on high-strength CNT yarns. "High-strength" reflects a systems study NASA did to determine how strong the materials needed to be for aerospace. The study analyzed the tensile properties. In her example, the baseline material components came to 800,000, but doubling the mechanical processes creates an overall benefit of 200,000 pounds. An improvement in specific mechanical properties by a factor of two or three will permit substantial mass reduction in structural and non-structural components, and the mass savings could be large enough to change design concepts. It is important to be credible in the descriptions, to ensure the subject is something real that can be useful and meet the target properties. The CNT yarn composite is competitive.

That is the background for the topic for the Institute, which is also to be competitive with computational modeling and focus on distinctive features. The core elements include computational tools, experimental tools, and digital data for design. In addition to the 11 universities, there are two industry members, which will benefit but also offer feedback to ensure the project develops the right material.

The Ultra-Strong Composites by Computational Design (US-COMP) Institute organization includes four elements under the Technical Advisory Board (TAB) and Leadership Team: Simulation & Design Team (SDT); Material Synthesis Team (MST); Testing & Characterization Team (TCT); and Material Manufacturing Team (MMT). There is significant interchange across all four. The universities own the intellectual property, though they had to sign some Non-Disclosure Agreements (NDAs) with industry to obtain the materials. NASA interacts quite closely.

Dr. Siochi delineated the challenge of multiscale CNT composite modeling. US-COMP focuses all members on the same system and helps advance the scale. The models are being built based on real data. Graphics depicted molecular modeling and meso-scale modeling. US-COMP is working on a proof-of-concept Machine Learning (ML) algorithm for designing simple CNT/polymer composites, while also trying to test ML to see if it is useful here. This is unique to CNT. For those who think that computational modeling can help materials maturation, this will link to manufacturing. The Institute is developing both a new material and a new process. Mr. Free said this was very important and urged her to make the point that they are trying to establish a tool that could shorten the future and accelerate selections.

He added that there is a fear of composites on crew modules, which must be overcome. Dr. Siochi agreed. She has spoken about this to a hostile audience that maintains there are insufficient data, and it does indeed take time to gather data. The project has embraced the game changing philosophy. They want to get to prototyping to address the real challenges and not just do science for the sake of science. This will call for a demonstration. Mr. Free agreed that this is a way to get people comfortable. It is an emotional discussion. Mr. Reuter also agreed, stating that there is a need for multiple demonstrations, beginning on the ground. This has been a long journey. Dr. Mountain advised saying "we need materials with these properties, and we need a path to development." Dr. Siochi cited the need for quantifiable objectives. It has been hard to convince researchers to use this method. Mr. Free recommended stating the vehicles on which it can be implemented, and the applications.

Dr. Siochi described how growth conditions flow to production, spinning of composites, understanding of the materials, and load transfer. To obtain the mechanical properties, the tubes need to be flattened, and to be flattened they must be a certain diameter. Flattened tubes are packed more efficiently than when they are round. In experimental characterization, standard test methods tend to call for a lot of sample, but US-COMP is trying to develop a way to test a smaller amount on a smaller scale. The miniaturization has shown replicability. Dr. Siochi described modeling and characterization for the Materials Genome

Initiative (MGI) efforts and noted some of the publications. NASA's internal efforts through 2015 led to the yarn and the increase in strength. The collaborative, multi-disciplinary partnership falls into six areas, and there are other funding mechanisms involved. Many of the members know they can move it forward due to other work often funded by other agencies. US-COMP believes the Institute can make this relevant for NASA in a timely manner.

The optimized goal is three times base strength. Mr. Reuter said that STMD is trying to emphasize use of the entire portfolio, and this is an example. He hopes to have six of these institutes, adding two every other year. The next round will be revolutionary propulsion and habitation. These institutes receive funding for 5 years, and the goal is for them to become self-sustaining. However, NASA will need to evaluate how to enable that, as it is rather challenging.

Dr. Ballhaus asked about the potential to overcome some of the unpleasant experiences with composites, and whether there will be the capacity to detect defects and certify repairs to enable use. Dr. Siochi said that US-COMP seeks understanding of how the materials behave, and an element of that is damage and damage mechanisms. Repair might involve resin. Other work is studying self-healing properties, though that is not part of this effort. The Institute's first step is to develop the material and enable lighter structures than what we have now. Dr. Ballhaus observed that spaceflight operates at the edge as it is. Dr. Siochi replied that CNT has other attractive properties. The Institute is looking at what advantages are enabled for flight control, for example.

Office of the Chief Technologist Update

Dr. Douglas Terrier, NASA Chief Technologist, provided an update from the last meeting's discussion. He is now officially the Chief Technologist after two years in the acting position. His primary role is advising the Administrator and serving as innovation champion for the Agency. Each NASA Center has a chief technologist. Along with his Headquarters staff and the NASA Technology Executive Council (NTEC), they inform the advice he gives. There are three buckets of work: innovation initiatives, strategic integration, and the Science and Technology (S&T) partnership forum.

Office of the Chief Technologist (OCT) initiative areas include the technology integration framework, innovation framework, S&T partnership, technology studies, and digital transformation study. A workshop allowed OCT and STMD to hear from executives in non-space companies who went through some of the same processes as the commercial space industry and had to go through major transformations in order to stay in business. "Young innovators" in the Agency also provided their perspectives. Not everything was positive, but it was good to hear.

There are four technology thrusts among NASA's four mission directorates, and OCT seeks to understand them in a cohesive framework. Starting at the top, with mission goals, helps each mission directorate identify their needs in a phased way. The next step is to identify the key technological challenges to overcome. Each mission directorate does a great job organically, but OCT wants to have a structured process, show synergy, and minimize overlap. OCT has not found a lot of duplication despite the outside belief that it exists, and a more rigorous process will help solidify that. There is now a very active community on technology integration. Dr. Terrier presented the framework steps by mission directorate. There are some gaps, but it overall looks good.

The Interagency Science and Technology Forum (ISTF) meets three or four times annually to discuss S&T collaborations. The Forum selected four priority areas from an initial list of 16 critical needs: smallsat technology, which has completed its work; big data analytics, which slowed down due to National Reconnaissance Organization (NRO) personnel issues; in-space assembly, run by NASA and going well; and cybersecurity, which is largely in the classified arena and making progress. The teams have identified common vulnerabilities and sponsored some gaming exercises. The November industry forum brought in the external perspective and resulted in a lot of agreement on potential future demonstration areas.

For the innovation framework, OCT surveyed the community to identify initiatives already in place. An example is that many young people say they do not have time or funding to be creative or develop new ideas. An early career initiative now offers awards supporting these activities. There is also an effort to get away from seeing innovation as fuzzy to understanding that it is a critical element. Most large industry organizations in each sector face similar barriers. One solution is having mission-specific outcomes to which all innovations can be traced. This will help identify gaps and extraneous projects. Another issue is preparing the workforce and succession planning. Innovation is integral to creating value. The diversity conversation is incorporated here, as opposed to being held as something separate. The National Academy of Sciences (NAS) has been helpful. Most work, investment, and speed are outside NASA. The Agency's innovation culture is therefore falling behind in terms of speed. The workshop looked at what would happen without change and had early career people speak to leadership.

In parallel, OCT has created a digital framework and run several studies to determine what is going on outside NASA. Working with companies beyond the normal circle has uncovered common challenges and approaches from which NASA can learn. It seems that NASA defines a lot of TRL advancement based on components, and that may call for assessment. Some human exploration work has been on the table for 30-40 years with little progress, and now 94 percent of the market is external.

The Digital Transformation (DT) study is being done in conjunction with NASA's Chief Information Officer (CIO). This is about using and integrating advanced digital tools to enable better outcomes, efficiency, etc. The effort has identified 180 success stories and more than 240 opportunities for further application of DT. OCT has been challenged to identify the more immediate activities that can be addressed in the next budget cycle. Other government agencies and industry have all been moving forward on this.

STMD Update (continued)

Mr. Reuter said that the decision on any reorganization will come soon. A lot has happened across the Agency since TI&E's last meeting. When the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (INSIGHT) mission landed on Mars, the cubesats came from STMD. They were part of a demonstration to provide communications and power at no weight and were a big success. The Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer (OSIRIS-REx) is now at Bennu, in the gravitational field. The Soyuz launch was both successful and a good story. The Cygnus cargo launch had two STMD items and the recent SpaceX cargo launch included the last of three robotic refueling tests. SMD's CLPS announced nine contracts for a platform for science and technology payloads, and these will result in some easy projects to demonstrate soon. There is an S&T Research Opportunities in Space and Earth Sciences (ROSES) call through SMD, for which the two mission directorates are determining funding. The platform for small landers and the Gateway will offer opportunities to researchers and early career individuals. Power and propulsion elements should be awarded early next year. The mission directorates are working together on lunar exploration.

Mr. Reuter returned to the investment strategy, repeating that a full-year CR is the worst-case scenario. He may have to find another $150 million to make Restore-L work. The Senate budget would be more manageable than House budget in that regard. STMD is to focus on exploration of the Moon, with an eye on Mars and LEO, keeping commerce in mind. Any science work beyond low TRLs must also support human exploration. As STMD is supposed to work across the TRL spectrum, its stance is that eight percent of its budget will go for low TRL work, defined as stages 1-3 and sometimes 4. This percentage has been well received. STMD prioritizes technologies being ready for flight, Solar Electric Power (SEP) being an example.

The Deep Space Atomic Clock (DSAC) is ready for launch, and laser communications is a priority. SEP has presented challenges; a technically viable but tight schedule will get the project to 2021. HEOMD provides the flight hardware. FY19 is an issue here, and there will probably be a need to take some descope options. Laser communications is through I&T and on path to complete within cost and schedule. The bus provider for the Air Force is substantially behind, however, with a six-month delay at best. This will carry a cost increase, and NASA is potentially liable for some of the cost overrun; it is in negotiations now. MOXIE was to be delivered this month for environmental testing with the spacecraft but requires retesting due to some technical problems. The new delivery window is March, and this carries a $5 million hit. A navigation instrument for Mars 2020 has been delayed but this is not against STMD's budget. Two Tipping Point solicitations focus on the Mars 2020 unit that industry plans to take to the Moon. The Mars Science Laboratory (MSL) Entry, Descent, and Landing Instrumentation 2 (MEDLI2) has some challenges and the team is looking at how Lockheed put the heat shield together.

In the lunar area, STMD is working from seven categories. First is Technology Demonstration Missions (TDMs), like precision landing. There is a strategy that starts with the CLPS landers, to which the effort will progressively add elements. The team is also repurposing a science computer. The next priority category is CFM, which has a lot going on and which allows some budget movement without damage. Third is kilopower, which is in pre-formulation to determine if it warrants flying. After that is ISRU, which has more of a shopping list than a plan; it would be impossible to do it all. The prospecting – identifying where water is – will be an SMD activity, and STMD will do the rest. High-mass Entry, Descent, and Landing (EDL) is fifth. STMD has an agreement with ULA to demonstrate the hypersonic inflatable accelerator on Earth. ULA suspects there is commercial potential for this, but NASA does not need it. Sixth, In-Space Robotic Manufacturing and Assembly (IRMA), has completed some Tipping Point work, and there are further proposals. However, it would be difficult to fund this, as it would be expensive. Finally, rapid transit propulsion will, in the longer term, involve NTP. There are no cost extensions on this, but STMD will maintain the research institution on propulsion. NASA will protect this, and other agencies might contribute as well.

Mr. Reuter listed the budget threats that must be addressed in the worst-case scenario. SEP, MOXIE, laser communications, and rapid transit fuel would stay, as would the institutes. There would be no major starts on IRMA. LOFTID has been cut and delayed despite some substantial impact, but there is enough to keep it going. Kilopower will hold to the FY18 budget. CFM does not need as much funding as projected. The next Tipping Point solicitation goes out in January. There would be no change for precision landing or high-performance spaceflight computing. About 30 percent of Game Changing Development (GCD) would be cut, but there is overlap with Small Business Innovation Research (SBIR). Early stage work and the institutes will remain, as will the early career initiatives and the low TRL funding. NASA Innovative Advanced Concepts (NIAC) will not start until FY20. STMD tries to get its obligations early in the year, but some awards are later nonetheless, so the August awards will move to October. SBIR and the Small Business Technology Transfer (STTR) programs will be commensurate with the overall funding level. STMD will fully fund ongoing Tipping Points but defer funding of new ones or ACOs until FY20.

What would remain as law on a CR would be the SBIRs, Restore L, and some employees. NTP has usually been in the report language. Flight Opportunities is a high priority of the Administrator, and there will be a call with more funding if the proposed work meets NASA needs on certain topics, with amounts between $350,000 and $500,000. There are also payloads on commercial vehicles, in which case they control the time.

Dr. Mountain asked what TI&E could do that would be helpful. Mr. Reuter replied that STMD is trying to show its progress and the potential impacts on its investments. Not all agree that university work or early stage are priorities. Nor does everyone agree that the technology development funds must be set aside. He would like TI&E feedback for improvement. Dr. Ballhaus noted that there have been good stories about what is flying now and what it took to get there. The skeptics ask what you did to move the needle on things we care about. A few good success stories are always helpful. Mr. Reuter said that he could get that into charts and try to get each program to show infusion paths and success stories. It could be a topic next time. Dr. Ballhaus urged him to show the payoff where STMD succeeds. Mr. Reuter wants to show it across the portfolio.

Gateway and Habitation Capability Development – HEO Tech Development Efforts

Mr. Jason Crusan, Director of Advanced Exploration Systems (AES) in HEOMD, noted that AES often collaborates with STMD. The overarching policy derives from Space Policy Directive-1, which is about enabling human exploration across the solar system. Trying to orchestrate the human spaceflight plan accomplishes that. AES checks its plan against eight guiding principles, which he described. It is important to be robust and resilient, and to continue learning. There must be technology on-ramps. The gradual build-up of capabilities is something NASA has done well with science on Mars but not with human exploration on the Moon; despite having landed on the Moon decades ago, NASA left no infrastructure there on which to build. New players and policy changes call for resilient and open architectures. NASA is strong in global collaboration and leadership. There must also be continuity of human spaceflight. The gaps have been extremely painful to learn from.

The Gateway is part of a much larger exploration campaign. In order to bring in new players over time, NASA wants to communicate the standards the Agency will follow, the international docking standard being an example. Avionics is another example, in which NASA and its international partners have agreed on four categories of standards. For power, there will be quality and variance standards with criteria. Other standards are more prescriptive. AES has worked with industry, international, and other organizations on these, receiving thousands of comments in the process. Open architecture creates opportunity. Cislunar space is a deep space harbor for exploration missions. Mr. Crusan described the location and environmental attributes sought for the Gateway, which will be in a Near Rectilinear Halo Orbit (NRHO) with selected focus on the north or south poles. It will require minimal orbit maintenance. One concern is eclipses, and the NRHO has almost none.

In the area of human lunar lander development, Mr. Crusan noted that Advanced Cislunar and Surface Capabilities (ACSC) will involve a 2024 demonstration. SMD is soliciting small lunar landers, while STMD is seeking the mid-sized landers that will lead to the human-class landers under HEOMD. NASA is moving toward buying services on the small landers. The Agency is revisiting options for how to do lunar landings. Mr. Crusan described the characteristics of one-, two-, and three-stage landers. Single stage does not even fit on a launch vehicle, while three-state does. In discussing the transfer vehicle, and ascent and descent elements, he noted that these do not have to come from the same supplier. In thinking about commonality, crew survivability will be in the ascent element, which will be the high-reliability element. NASA wants industry studies on this, and further trades can be done. For example, the Agency has not chosen the propellant and would like industry to be involved in that.

In discussing the use of the Gateway versus direct flight to the Moon, Mr. Crusan noted that while direct flight requires less energy, there is no way to do it as a single launch. He also described transfers in terms of the energy used. Direct flight costs less overall, but the Gateway enables reusability for only a six percent penalty. In addition, the Gateway is not really new, having been part of the Mars architecture all along, where it was the unnamed concept of a dry dock location. Mr. Crusan reviewed the Gateway objectives, including crewed missions, science requirements, proving ground and technology demonstration, and partnerships. Crews should be international, with a minimum of four astronauts. At 50kw, the Gateway will be about 10 percent the size of ISS. Cargo resupply will need to be where the international partners can reach it. It will be incredibly efficient, with more than 2 tons propulsion. Another consideration is the need for a heavier Power and Propulsion Element (PPE). Mass as a limiting factor is more about speed of response, use of fuel, and rendezvous with docking. There may be campaigns in varying orbits to accommodate various needs.

NextSTEP-2 addresses deep space habitation prototypes, for which there have been six studies run; they vary quite a lot. The intent is to understand options. Further testing will occur at NASA Centers and vendor facilities. Much of the testing is on human factors. A February science workshop was done in conjunction with SMD and life sciences. NASA published the external payload interface. A systems requirement review, called the Formulation Sync Review (FSR), was kicked off in September. The schedule is incredibly aggressive, and there are issues with the acquisition process. This is a safety culture change, because NASA is not human-rating everything. The Gateway will operate like a science payload, raising questions of balance. The high reliability of Orion will help, but NASA is also buying certain items without testing them completely. While seeking the most robust system possible, there is always the chance NASA will make a wrong decision. There are also limiting factors, like power transfer.

Dr. Mountain asked about protecting astronauts from radiation. Mr. Crusan explained that Orion has a storm shelter and the expectation is to have shielding on the Gateway. NASA has provided each vendor with the radiation impact modeling tools. The Agency will also monitor secondary effects. The Gateway will have an airlock capability for science and other payloads. The assembly assumes no need for human intervention, and there will not be a lot that can be fixed on the outside, though the Gateway will have the capacity to put a crew member on the outside robotic arm.

Discussion and Recommendations

Mr. Green said that the NAC was to meet the next Monday afternoon, and all of the committees were limited to 30-minute presentations. TI&E was scheduled for second to last, with the last one being a new policy and regulations committee that should take a lot of time and could be contentious.

Dr. Ballhaus said that this was an opportunity to present TI&E thoughts to Mr. Bridenstine, noting that much of what they were likely to say had been presented to the NAC and not gotten much pushback. He began assembling charts from the March presentation. Dr. Mountain had also sent two slides for consideration: an interview with NASA's second administrator, Mr. James Webb; and the unamended National Aeronautics and Space Act of 1958 that founded NASA. Dr. Mountain was concerned that a reorganization might damage NASA's technology program. It was agreed to start with a statement that "The Space Policy Directive-1 provides a near-term destination for which a detailed program plan could be formulated along with required technologies and need dates."

The next point was that technology budgets have been disadvantaged by lack of an urgency argument. Dr. Desai pointed out that the overall approach to restructuring was open and not decided yet. It was decided not to include a slide on this, but to mention it. Other points to be made addressed the lack of technology funding prior to STMD's inception, the university relationships, and the roadmap. It was important to ask how NASA will protect its "seed corn" and university mechanisms without STMD. The other mission directorates find technology development funds as dispensable, thus diluting and delaying NASA's overall technology effort. It was agreed to include the August NAC recommendation, the NASA response, and the letter. Mr. Green said that he and Dr. Mountain would work on editing and formatting after the meeting. They agreed to include a photo of Times Square filled with people watching the recent INSIGHT landing, showing that the public cares and follows. While INSIGHT is a science mission, the EDL was an engineering effort.

Adjournment

Mr. Green thanked Dr. Ballhaus for his service as TI&E chair. NASA has a commemorative gift for him in the form of a medal. Mr. Reuter also thanked him.

The meeting was adjourned at 3:08 p.m.

Appendix A

Agenda

NAC Technology, Innovation and Engineering Committee Meeting
December 7, 2018
NASA Headquarters
MIC 6A&B
300 E Street, SW, Washington, DC 20546
Dial-in number: 1-844-467-6272 Pin Code: 102421

December 7 – FACA Public Meeting

8:00 a.m.	Welcome and Overview of Agenda/Logistics Mr. Mike Green, Executive Secretary
8:05 a.m.	Opening Remarks Dr. William Ballhaus, Chair
8:10 a.m.	Space Technology Mission Directorate (STMD) Update and Discussion Mr. James Reuter, Associate Administrator (Acting), STMD
8:30 a.m.	Cryogenic Fluid Management Update Ms. Dayna Ise, Acting Technology Demonstration Mission Program Executive, STMD
9:15 a.m.	In-Situ Resource Utilization Planning and Update Mr. Gerald Sanders, Systems Capability Leadership Team Lead, NASA Johnson Space Center
10:00 a.m.	Break
10:15 a.m.	Ultra-Strong Composites by Computational Design Space Technology Research Institute Update Dr. Mia Siochi, NASA Langley Research Center
11:00 a.m.	Office of the Chief Technologist Update Dr. Douglas Terrier, NASA Chief Technologist
11:45 a.m.	Lunch
1:00 p.m.	Gateway and Habitation Capability Development – HEO Tech Development Efforts Mr. Jason Crusan, Director, Advanced Exploration Systems, HEOMD
2:00 p.m.	Space Technology Mission Directorate (STMD) Update and Discussion Mr. James Reuter, Associate Administrator (Acting), STMD
2:45 p.m.	Break
2:55 p.m.	Discussion and Recommendations
4:30 p.m.	Adjournment

The WebEx link is https://nasa.webex.com/, the meeting number is 904 275 701, and the password is "N@CTIandE1218" (case sensitive).

APPENDIX B

Committee Membership

Dr. William Ballhaus, *Chair*
Mr. G. Michael Green, *Executive Secretary*
Mr. James Free, Peerless Technologies
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:
Charles (Matt) Mountain, *Acting Chair*
G. Michael Green, *Executive Secretary*
William Ballhaus, Jr. (via teleconference)
James Free
Kathleen C. Howell
Michael Johns
Mary Ellen Weber

NASA Attendees:
Garry Burdick
Jason Crusan
Prasun Desai
Dayna Ise
James Reuter, *STMD Acting Associate Administrator*
Gerald Sanders
Mia Siochi
Douglas Terrier
Anyah Dembling

Other Attendees:
Matthew Leonard, GCN
Amy Reis, Electrosoft
Elizabeth Sheley, Electrosoft

WebEx:
Darrell Branscome
David Eisenman
Karen Fisher
Wesley Johnson
Kurt Sacksteder
David Steitz
Gerald Voecks
Robert Wallace

APPENDIX D

Presentations

1) Cryo Fluid Management Planning [Ise]
2) In Situ Resource Utilization Planning and Update [Sanders]
3) Computationally Accelerated Materials Development for Ultra High Strength Lightweight Structures [Siochi]
4) Office of the Chief Technologist Update [Terrier]
5) Gateway Update [Crusan]