National Aeronautics and Space Administration

Technology, Innovation & Engineering Committee of the NASA Advisory Council

NASA Ames Research Center
Moffett Field, CA
August 28, 2018

Meeting Minutes

______________________________ ______________________________

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

TABLE OF CONTENTS

Meeting Report prepared by
Elizabeth Sheley

NAC Technology, Innovation, and Engineering Committee Meeting
August 28, 2018
NASA Ames Research Center
Moffett Field, CA

Open Meeting

Welcome and Overview of Agenda/Logistics

Mr. Mike Green, Executive Secretary of the NASA Advisory Council (NAC) Technology, Innovation and Engineering (TI&E) Committee, welcomed the members and thanked the Ames Research Center (ARC) staff who took the members on a tour of the Center the previous day. He then reviewed the meeting agenda. He noted that because Dr. William Ballhaus, TI&E Chair, was unable to attend the meeting, Mr. James Oschmann would serve as chair.

Opening Remarks

Mr. Oschmann welcomed the Committee members. He looked forward to the meeting discussions and the follow-up from the previous meeting.

Welcome to NASA Ames Research Center

Dr. Eugene Tu, ARC Director, welcomed the TI&E members and provided an overview of the Center. ARC projects address all of NASA's priority areas, enabling cross-cutting activities. An example is autonomous systems, which have long been relied upon for robotic and human space missions, and are now moving into aeronautics and aviation. While ARC's location in Silicon Valley is expensive, it also promotes a great deal of synergy, with personnel moving in and out of ARC from the private sector. Ames has long history of innovation and thinking outside of the box, having begun in 1939 as a National Advisory Committee for Aeronautics (NACA) lab. Dr. Tu gave some examples of ARC innovations. The three major phases of the portfolio are aero-thermal dynamics, space and science research, and information science and technology research. ARC has adapted to what NASA needs.

The Center has around 2,600 employees, about 1,200 of whom are civil servants. ARC took over Moffett Field from the Air Force and turned it into a research park to enable on-site partnerships and bringing in another 1,600 tenants from industry, academia, and other government agencies. In addition, the U.S. Geological Survey (USGS) will locate another 500-plus scientists at Ames over the next few years, building on existing NASA-USGS partnerships in Earth and planetary sciences. With a Fiscal Year 2018 (FY18) budget of $918 million, ARC offers a major wind tunnel facility, supercomputing facilities, space for work in Entry, Descent, and Landing (EDL) technologies and more.

Among ARC's eight core competencies are entry systems; intelligent/adaptive systems and human interactions with these systems; and cost-effective space missions. Partnerships address such topics as research into quantum supercomputing, with Google and Carnegie Mellon University. Partners span the range and include commercial, international, academic, and inter-agency entities. ARC hosts a number of virtual institutes as well.

Space Technology Mission Directorate (STMD) Update and Discussion

Mr. James Reuter, Acting Associate Administrator for NASA's Space Technology Mission Directorate (STMD), said that the FY18 operating plan was recently approved. A proposed restructuring will focus on technologies to enable NASA's exploration campaign. This campaign will begin with a return to the Moon and will enable both human exploration and science. The proposed Lunar Orbital Platform and Gateway (Gateway) envisioned for cislunar space will enable lunar exploration and science, and while also serving as a platform for future Mars exploration. The first element to launch, the Power and Propulsion Element (PPE), is planned for 2022 in partnership with the commercial sector. NASA will focus on the challenge of Solar Electric Propulsion (SEP), and is currently addressing technical issues identified in the recent Preliminary Design Review (PDR). The Orion crewed mission is targeted for 2022 as well. The flight sequence depends on funding.

For exploration of the lunar surface, there is a need for lander capabilities, and NASA is particularly interested in purchasing small commercial landers. A Request for Proposals (RFP) is out in order to determine response. There is no size designation in the RFP, but the expectation is that these will be in the 100 kg range. Mid-sized landers will fall to the Human Exploration and Operations Mission Directorate (HEOMD), and may weigh two metric tons. These could evolve into human-sized landers of 5-10 metric tons. The smaller landers are demonstration platforms for science, led by the Science Mission Directorate (SMD). Along with SEP, precision landing will be very important; the goal is to become increasingly specific. Some of these technologies can be demonstrated on Earth. In addition, computing systems will need to be more robust than those recently tested.

The Mars 2020 mission will carry four STMD instruments that will be able to feed back to other efforts. At this point, the mid-size robotic lander is not drawing great commercial interest, but NASA expects that to change. The Agency is conducting some trade studies. The intent is to apply NASA expertise to the evaluation of these efforts, looking in both directions so that previous and existing reliability criteria do not preclude innovation. Cryogenic Fluid Management (CFM) is an area that NASA needs to advance in order to enable these systems, and this might be a future TI&E meeting topic.

Among Tipping Point topics, STMD made several selections leading toward some critical technologies to demonstrate, for about 10 demonstrations altogether. Along with precision landing and CFM, one of the urgency areas is what to do upon returning to the Moon, through the lunar days and nights, each of which lasts about 14 Earth days. Sustained operations will require an alternative source of power. PU-238 is not a long-term solution, as it has limitations. STMD conducted an experiment with the Department of Energy (DOE) investigating kilopower with a 1 kw demonstration unit. The investigation will use 2019 as a pre-formulation period, and trade studies are ongoing. The demonstrated unit should be scalable to 10 kw. HEOMD wants 40 kw, which should be doable.

The next issue is how to use the Moon and lunar surface. A key area is In Situ Resource Utilization (ISRU), with activities like finding and processing water, etc. STMD manages ISRU for NASA and has made some low-level funding awards in this area, with the goal of scaling up. There was also a quick study on what NASA could accomplish rapidly on a small commercial lander. This drew 130 suggestions, many of which are fairly simple and are now being built into the plans. STMD's strength is its breadth, including its partnerships, so the Directorate is trying to use the whole portfolio to enable some of these activities. Mr. Reuter said that he had more detail about the technologies involved, but he could not show that chart because it was embargoed at the moment. However, STMD is infusing multiple items into each element of the exploration plan, and clear connections will be obvious soon.

Due to the proposed restructuring, the FY19 PBR of about $1 billion does not have a direct, line-by-line correlation with the FY18 appropriation. The proposed restructuring would move the Human Research Program (HRP) and some Advanced Exploration Systems (AES) activities currently with HEOMD to the STMD budget. Those programs have complementary technologies, and the work division has not always been straightforward. In addition, the reorganization plan has evolved since it was introduced. The FY18 STMD budget is $760 million, and the FY19 PBR figure would be about $860 million if HRP were moved out of STMD. However, the Agency wants to keep HRP with HEOMD. As the budget goes forward, the details are being worked out.

The AES content would move to multiple places. For example, habitation systems are staying with HEOMD, while STMD focuses on low Technology Readiness Levels (TRLs). AES was developing five cubesats that are now with STMD, and some funding for the Mars Oxygen ISRU Experiment (MOXIE) and other projects has shifted to STMD. Other systems are more appropriate for HEOMD. The Agency is trying to be smart about this while following FY18 rules and waiting on the FY19 appropriation. Neither house of Congress has addressed this in their mark-ups, nor is it on the schedule. Therefore, HEO-specific work is being left there, with STMD taking on many of the jointly funded activities. This has been hardest for those working on the projects, as they must change their processes. NASA wants to sustain anything that is going well.

Dr. Mary Ellen Weber asked if there were any items not being funded in the FY19 PBR that Mr. Reuter would otherwise expect. He replied that things that are uniquely science are falling off the table, like the Wide Field InfraRed Space Telescope (WFIRST) coronagraph, which had just reached TRL5. Some Thermal Protection System (TPS) work is being picked up by SMD, along with other activities. Dr. Weber observed that in the past, shrinking budgets for STMD have meant technology demonstration cuts, and wondered if that were an issue here. Mr. Reuter said that it was too early to determine that.

He showed the status of the FY19 appropriations. The two huge drivers for the STMD budget have been Restore-L/Satellite Servicing and Nuclear Thermal Propulsion (NTP). The latter is not a driver for returning to the Moon, but it will be important for more distant exploration and will be ripe for a major demonstration. It can be very expensive. There are some major discrepancies in the House and Senate mark-ups for both Restore-L and NTP, which could affect other programs. He noted that the deflatable lander has strong commercial interest. A prioritization decision is needed for the approach to Restore and NTP, as the two houses of Congress have quite different figures in the mark-ups. Specifically, Restore has $130 million from the House and $180 million from the Senate, with $45.3 million in the PBR. Meanwhile, the House would fund NTP at $150 million and the Senate at $75 million, compared with $58 million in the PBR. Furthermore, language from both the House and Senate indicates a desire for HRP to remain in HEOMD, with mixed direction on AES content. Depending on the final outcome, the direction could have a significant impact on the STMD portfolio.

Dr. Weber pointed out that both the House and Senate exceeded the FY19 PBR amounts, and asked about the source of the extra funds. Mr. Reuter said that the House and Senate will have to work things out, then NASA will talk with them. He emphasized that STMD has good interactions with Congress, and the priorities align. The current House budget for STMD is $900 million total and the Senate bottom line is $933 million. These figures do not include HRP. The numbers are not as dire as they look. Dr. Weber said that this all looks quite rosy. In the past, TI&E has focused on the cuts that must be absorbed, and she wanted to know the likely prospects for cuts. Mr. Reuter said that he could not discuss some of this, as it is in the negotiations, but he would expect cuts to come from things less directly related to exploration. SEP is critical, so it will not be cut. However, other activities might be slowed, delayed, deferred, etc. Early stage activities comprise about eight percent of the budget, and STMD is trying to tie them to payload delivery. The goal is to have each early stage program include some funds for transitioning. Mr. Michael Johns noted that there were some big variables, and the Senate has rejected the reorganization, in which case the numbers are even better. Mr. Reuter said that Congress is supportive, so STMD will need to work to show them what the Directorate is facing.

Mr. Reuter concluded the presentation by providing data on STMD impact and accomplishments. For example, 850 other entities have picked up projects after STMD completed its work on them. In the last year, STMD has made a number of Tipping Point awards for directly infusible technologies; three of these were for $10 million. Other awards have gone for the Early Career program, ISRU, and CubeSat demonstrations. The Green Propellant Infusion Mission and Deep Space Atomic Clock projects are tentatively slated to launch in November aboard the Airforce STP-2 mission.

Regarding the restructuring, the PBR had proposed that STMD be reorganized, either by being absorbed into HEOMD or by having its functions divided up. Since then, NASA has been considering "hybrid options," including keeping HRP with HEOMD. This has gone to NASA Administrator James Bridenstine, who wants to know how the organizational structure will help promote the return to the Moon. He also wants to know where the chief architect of the return will be located. Dr. Weber asked whether, under the first option, HEOMD would have discretion to remove and reallocate space technology funds. Mr. Reuter said that Congress will have to approve any reorganization. In addition, there is some flexibility with funding, but there are also budget lines.

Autonomous Systems Capability Overview

Dr. Terry Fong, Senior Scientist for Autonomous Systems, described the Systems Capability Leadership Team (SCLT). Dr. Fong leads the Autonomous Systems SCLT, which began work in January of 2018. The SCLT is a community of practice that cuts across all NASA mission directorates, though most of its work is with STMD. It identifies barriers to infusion of autonomous systems, assesses the NASA workforce and facilities needs in this area, and makes recommendations for Research and Development (R&D) and investments. The 34 members represent all of the NASA centers and mission directorates.

Dr. Fong reviewed the distinctions between Artificial Intelligence (AI), automation, and autonomy. AI has no single, accepted definition, though the Defense Science Board defines it as the "capability of computer systems to perform tasks that normally require human intelligence" such as perception, conversation, and decision-making. AI encompasses many technologies and applications. Most NASA systems involve some degree of automation, which is not self-directed, instead requiring command and control via a pre-planned set of instructions. A system can be automated without being autonomous. Autonomy requires self-directedness and self-sufficiency to achieve goals and operate independently. It is not the same as AI or automation, and it can include humans as an element.

These definitions are important in determining the scope of the Autonomous Systems SCLT. Autonomy can be essential in addressing communications constraints, the timeliness of decisions, and more. NASA can use autonomy across many different areas, and there is a great deal of interest. An example comes from aeronautics and traffic management for large-scale systems. Safety and coordination are critical considerations. Similarly, the Gateway is not meant to be continuously manned like the International Space Station (ISS). Crew will be there only a small fraction of the time, which leads to questions about management. Much of the utilization will depend on the Gateway being continuously sustainable and functioning without the presence of humans, which means it will require on-board autonomous systems. There are many examples of science missions in which human direction will not be possible. The Europa mission will have a short duration, which precludes an approach in which project management can stop, analyze, and resume. Instead, the mission will need to have on-board autonomy and multiple options.

In the space technology pipeline, STMD is working to mature autonomous systems technologies to the prototype stage. In the area of air traffic management, there will be a need to avoid problems among autonomous, piloted, and remotely piloted systems. This leads to questions of how an autonomous system will communicate with Air Traffic Control (ATC), the pilot systems, etc. Autonomous systems and operations in HEOMD seek to address a number of areas of human spaceflight, to enable crew and vehicle independence from ground-based mission control.

Astrobee is an STMD robot slated to launch to the ISS in order to relieve the crew of a number of time-consuming tasks, such as inventory control and moving cameras around. The mission will serve as the starting point for some Gateway systems like in-flight maintenance. STMD is considering a number of autonomy projects, including distributed spacecraft autonomy, which involves controlling multiple spacecraft efficiently and managing operational complexity and costs. This project, in formulation for a proposed FY19 start, involves working closely with Starling, a partnership between NASA and the Air Force Research Lab (AFRL). The Integrated System for Autonomous and Adaptive Caretaking (ISAAC) will be to address care of exploration spacecraft, with a planned test on the ISS for infusion onto the Gateway. It will relieve astronauts of some routine work and will monitor and maintain systems in their absence. Some of the future autonomy R&D will address perception for extreme environments, reactive science, and collective operations. Some of these efforts will be too far from Earth for human involvement, requiring autonomous systems that can manage risk and uncertainty.

As noted, all of the mission directorates participate in Autonomous Systems SCLT activities, and there is support from NASA's Office of the Chief Engineer (OCE), Office of the Chief Technologist (OCT), and external government partners. Department of Defense (DOD) involvement is largely through AFRL. Mr. Oschmann noted that AFRL has done a lot of work in the area of human effectiveness. Dr. Fong agreed, adding that a core area is how to improve the effectiveness of humans, especially those who have to operate independently. A lot of work done by both AFRL and NASA focuses on the human ability to deal with large amounts of data, as well as with complexity. Mr. Oschmann observed that many ambitious science missions will require more autonomy. Dr. Fong said that that is also a factor in efficiency and costs. There is a need to balance SMD's conservative operational culture against the need to enable autonomous decision-making.

The autonomous systems taxonomy encompasses four areas and a range of activities that NASA has engaged in or must engage in in order to move forward with exploration. Dr. Weber said that at the Johnson Space Center (JSC), she saw the Boeing crew vehicle and checklist system, and they are very far along in achieving some autonomy in these procedures. She asked if SpaceX and Boeing were on board with the taxonomy presented here, or if they have their own charts. Dr. Fong replied that they have their own internal technology strategy teams, which are largely in line with those at NASA. The Autonomous Systems SCLT has been assessing NASA mission directorate needs before moving further out. The automated or smart checklists for crew will be helpful, but branching procedures can become an issue. Dr. Weber suggested checking with Boeing, as they are far along and will be flying soon. The algorithms are close to having the computers handle things themselves. Dr. Fong said that in terms of supporting astronauts, it assumes the presence of the necessary on-board computational capabilities and performance. Also, from risk point-of-view, quantification of risk with less hands-on control is a challenge across all of NASA. Mr. Johns said that the Defense Advanced Research Projects Agency (DARPA) is interested in swarm technologies. Dr. Fong replied that NASA is following a DARPA program on swarms.

Solar Electric Propulsion (SEP) Update

Mr. Todd Tofil, SEP Project Manager at NASA's Glenn Research Center (GRC), explained that the program seeks to develop SEP technologies and perform on-orbit demonstrations to advance maturation. SEP uses electricity to ionize atoms of a propellant, producing efficient thrust that reduces the amount of fuel carried into orbit. There has been increased use of SEP on commercial satellites. NASA's SEP effort includes the Advanced Electric Propulsion System (AEPS); in-house work with the Jet Propulsion Lab (JPL) on the Hall thruster and Power Processing Unit (PPU) risk reduction; the SEP Testbed; and the Plasma Diagnostics Package (PDP), which is in formulation. The team is currently focused on the PPE and is altering the contract so the contractor, Aerojet Rocketdyne, will procure the electric propulsion strings for the mission.

SEP is important to the PPE, which will be the first element of the Gateway, targeted to launch in 2022. At a minimum, the Gateway will consist of a PPE and habitation, logistics, and airlock capabilities. Aerojet is developing a 13kw electric propulsion string to support multiple future space missions. The contract is being modified to pull the qualification string from the option period to the base period. The general approach of Aerojet has been to build and test the design quickly instead of spending a lot of time on analyses. The three main components are the PPU, the Hall Current Thruster (HCT), and the Xenon Flow Controller (XFC), which interfaces with the PPU. This HCT is the first to be magnetically shielded to prevent degradation of the shielding wall. That is a key development to support long-duration missions. An Aerojet system PDR identified some issues. Subsequently, the company redesigned the Discharge Supply Unit (DSU). The new system tests integrated the DSU breadboard, showing that the PPU design would perform well. The team has since moved on to develop a plan to deliver a qualification string to SEP. Some programmatic and technology areas remain open, including some schedule catch-up and the contract modification. Meanwhile, the team is looking at the thruster and PPU in terms of thermal and structural capabilities under high shock loads.

Next is in-house work on risk reduction, life qualification, and in-line tasks, some of which overlap. In-line testing under the Aerojet contract must be done at a NASA facility. Mr. Tofil described selected in-house accomplishments. The Technology Demonstration Unit 1 (TDU-1) testing has been done on laser-induced fluorescence, which factors back into the model. Also, TDU-3 addressed wear testing. This involves long-duration tests with periodic analyses, resulting in some unanticipated items that have been fed into design adjustments. TDU-2 addressed certain vulnerabilities. Other testing included accelerated carbon deposition tests. NASA's thruster testing seeks to stay aligned with the Aerojet design and testing, while backing it up with independent testing.

The PDP, which is still in formulation, will collect data on the plasma environment produced by the HCT. Goals include eliminating some of the unknowns and margins from the EP design, and validating models of high-power SEP operations. The final area of focus is an in-house SEP testbed, which is modular and can be reconfigured. This is in the integration phase, and will be capable of testing two thrusters simultaneously. SEP project plans for the next several years involve continuation of current activities, and planning for PPE. The overall message is that there is now an EP string in development that will support PPE. A strong in-house team is supporting that work. The testbed is progressing, and the PDP is now underway and appears to be on a good path forward.

Office of the Chief Technologist Update

Dr. Douglas Terrier, NASA Chief Technologist, explained that his role is more at the strategic and policy level, to advocate internally and externally while supporting innovation. OCT covers the entire portfolio across all NASA mission directorates. Much of the focus is on STMD, but there is significant technology investment in each of the other mission directorates. Each of the 10 NASA centers has a chief technologist. There is also a NASA Technology Executive Council (NTEC) involved, with a working group to ensure that all of the studies in the Agency are in sync. Science and Technology (S&T) partnerships, strategic integration, and innovative initiatives are the three focus areas.

The Science and Technology Partnership Forum (STPF) constitutes a very productive relationship with many other government partners to identify common technology requirements and ensure understanding of the investments and synergies involved. The Forum identified critical needs, selecting four priority areas for collaboration from an initial list of 16. The Space Council has drawn attention to these activities. The goal is to hand them off to operational staff. The Air Force chairs the Small Satellite Technology area, the National Reconnaissance Organization (NRO) manages the Big Data Analytics effort, and NASA is responsible for both In-Space Assembly and Cybersecurity. These activities occur at the chief scientist and chief technologist levels among the participating agencies, with the administrators of the agencies discussing it as well. There is also some emphasis on autonomous and cislunar areas.

Among the strategic integration elements is a collaborative working environment, which is a new approach for OCT. The Office is trying to provide investment and other advice to the Administrator's office, while also seeking synergy across the mission directorates. There are six current strategic integration studies, which Dr. Terrier listed. The chief technologists of the centers are pulling people onto these efforts, and there is contractor support as well. Much of the effort is about benchmarking. NRO and the Air Force are wrestling with some of these same issues.

Digital transformation involves fully leveraging digital technology to transform NASA's processes, capabilities, and products to maximize mission success. In 2017, the NASA team completed a scoping study on this, determining that the Agency is not doing enough when benchmarking against other agencies. Steps forward include identification of the latest developments in digital technologies and applications; identification of ongoing digital transformation efforts and the perceived needs; and external benchmarking. Mr. Oschmann noted that ARC has a partnership with Google on quantum computing, and there have been huge efforts in the same areas in the medical community. He advised benchmarking and identifying some of the less extensive examples of activities that would bring about change. Dr. Terrier agreed, explaining that the initial focus is on the "low-hanging fruit."

The strategic integration framework incorporates national policy, Agency-level strategic plans, or other activities that drive missions. Each mission directorate has done a good job of identifying and thinking in terms of the trends through to the technology investments. However, the mission directorates all do things differently, making it hard to identify gaps and overlaps. OCT needs to be able to evaluate and advocate. The framework enables this by asking why (missions/outcomes), what (technical challenges), how (development strategy), and when (technology investment).

The innovation framework grows from the innovation culture, which is essential to achieving Agency missions within budget and schedule. OCT is trying to frame a study identifying 146 NASA innovation activities in terms of what the Agency wants to achieve, the characterization of the activities, and identification of gaps and overlaps. In identifying barriers to innovation, OCT is working with the National Academy of Sciences (NAS), which has planned a workshop for November to look at where NASA needs to be, what failure and success look like, and how to design from there. In this framework, the "why" links to mission outcomes. OCT has partnered with both mission support teams and diversity and inclusion efforts. A lot of innovation seems to lead to the need for diversity. The innovation framework links original ideas throughout the Agency to mission objectives; enables identification of, and strategic management of, barriers to innovation; promotes communication and knowledge-sharing; leverages existing resources; and provides stakeholder representatives with an agile development process. To this end, NASA has hosted two "Meetings of Experts" through NAS, in addition to the previously mentioned November workshop; funded "Innovation Without Boundaries" seedling projects at each NASA center; and inventoried and aligned current Agency innovation activities with the innovation framework.

Discussion

Following lunch and the TI&E members' annual ethics training, Dr. Oschmann led the Committee in discussion. Mr. Johns said that regarding technology infusion into missions, it was important to highlight in terms of how to map technology areas to the exploration objectives of the current administration. Mr. Reuter said that that was possible; he had an embargoed graphic on that, but he could provide more detail than what was in his presentation. Mr. Johns added that the urgency argument should address how the lunar timeline would be affected if the investments were not made. Dr. Weber noted that TI&E had recommended incentives for technology infusion in EDL, which the NAC had adopted; this recommendation was subsequently praised. Mr. Oschmann said that the Committee had also talked about incentives for proposing laser communication as an element in Discovery calls, which is ongoing. Dr. Weber said that it was in four proposals. They were not selected, but it was a good step forward.

Dr. Ballhaus, participating by phone, said it was nice to get the overview from Dr. Tu, who pinpointed progress and described discussions with Headquarters. It was also good to see the progress being made in the area of autonomous systems. Mr. Oschmann liked the evolution of thinking from the Chief Technologist and Chief Scientist, who are looking at collaborating both inside and outside the Agency. He has always struggled with the "Valley of Death" concept, because not everything can go forward, although it can be hard to assess. However, NASA should be able to match from the bottom up, and he also liked the efforts to tie things together from the top down. The morning presentations also showed good SEP progress, and Dr. Fong's SCLT on autonomous systems seems to be going in the right direction, especially in terms of coordination with other government organizations. Dr. Kathleen Howell agreed, though she would like to see more specific applications in the future. Mr. Johns said that with all of the activity in the commercial sector, it would be good to have an update from Dr. Fong in a year.

Mr. Oschmann said that in terms of budgets, the PBRs, and the Congressional mark-ups, it would be good to know where the potential issues might lie. Mr. Reuter said that that is handled internally. He is always thinking a year ahead, but is reluctant to be too open about options. Nonetheless, the range is $100-150 million for the budget hit. Dr. Weber said that TI&E might want to make a recommendation on the budget, and they could not do that so well without the information. Every time they have weighed in previously, it has been at this stage. Mr. Oschmann added that while the Committee does not want judgments and information Mr. Reuter is not ready to share, they would like to know where the shortfalls could occur. That would let them to give advice. Just a bit more information would help.

In-Space Robotic Manufacturing and Assembly (IRMA) Projects Update

Ms. Trudy Kortes, Technology Demonstration Missions (TDM) Program Executive, explained that the IRMA work was competed, and the award made in 2015. There are four mission managers, with the project based at NASA's Marshall Space Flight Center (MSFC). Three proposals were selected (Made In Space, Orbital ATK – now Northrop Grumman, and Space Systems Loral) with work started on a 2-year (1 base year, 1 option year) ground development effort through FY17 and FY18. There is an ongoing procurement phase for a Phase 2 flight demonstration.

Mr. Charles Adams, IRMA Mission Manager, added that these were Tipping Point solicitations. The Dragonfly program focuses on increasing the size and number of large solid reflectors on orbit while lowering costs, increasing spacecraft flexibility on orbit, and improving throughput. The goals are to demonstrate stowage techniques, modify assembly interfaces for robotic use, have antenna support structures that meet extremely high-performance requirements, and develop a feasible concept for augmenting an existing Geostationary Earth Orbit (GEO) satellite. ARC is the NASA teammate and Loral is the prime contractor. A lot was learned in the testing, which led to some changes. The program recently went through its closeout review and Critical Design Review (CDR). The team will eventually provide a detailed TRL assessment of everything that was done.

Mr. Adams reviewed some of the accomplishments, then showed graphics of some of the prototypes that were built. The team developed forms for the reflectors, built a prototype of the robotic arm, advanced the technology for the trusselator, and created other prototypes. The test facilities were advanced as well. The team also completed two concepts of operations demonstrations. A demonstration video showed the guide mechanism that locks the joint. Additional testing and other work is being completed for the final report, to be submitted in September 2018. The contract will end at that point.

Mr. Oschmann asked if there had been any coordination with the Satellite Servicing Office. Mr. Adams replied that Northrup Grumman, the contractor for the Commercial Infrastructure for Robotic Assembly and Services (CIRAS), is interacting with the Office. Mr. Oschmann said that it might be helpful to include that information. Ms. Kortes said that some of that happens organically. The various parties are aware of each other and talking, just not always through NASA. TDM is mindful of both the community of practice and the competitions. The previous hyper-competitive environment is a thing of the past.

Mr. Adams next described CIRAS, which is a robotic assembly, repair, maintenance, and refurbishment capability to enable satellite servicing and large space structure assembly. He described the technologies and listed the initial and final TRLs for the project. CIRAS involves a series of three vehicles. The Mission Extension Vehicle 1 (MEV-1) will dock with spacecraft and extend their life. The Mission Robotic Vehicle (MRV) is a fuel pod that will attach to spacecraft. The Mission Extension Pods (MEPs) will feed into long-range plans with additional capabilities. Assembly and construction flexibility were the drivers, and precision and accuracy were crucial as well. The goal is to build large, precise structures in space. To this end, the team developed a long-reach, lightweight robotic arm and controls; an articulated truss for robotic deployment; and jigging and placement robots for assembly of free-form truss. A video showed the arm being demonstrated in the lab. One of the objectives that was achieved was a modular reversible connector, along with a quick disconnect interface. The metrology system achieved some tight tolerances on the structures. The team identified Electron Beam Welding (EBW) as the preferred joining method. The tool for this is expensive, however, so cost reduction is a goal. EBW has to be done in vacuum at present. Mr. Adams showed the pending and completed work.

Mr. Lawrence Huebner, TDM Project Lead, described the Made in Space (MIS) Archinaut system, which has the goal of robotically creating spacecraft and extremely large structures in space. This will reduce spacecraft costs and the mission constraints created by launch loads and volumes, while also reducing risk to astronauts during assembly. Much of this involves 3D printing, in which thermal polymer printing puts down layers via an extruder. However, heat becomes an issue and the technology had to be demonstrated; thermal vacuum testing had begun just the previous week. Some of the Phase 1 accomplishments include additive manufacturing, verification and validation, and robotic assembly. The preliminary results review will take place in mid-September, and the Phase 1 close-out review was planned for late October.

Center for the Utilization of Biological Engineering for Space (CUBES) Update

Dr. John Hogan of ARC said that CUBES was at the end of its first year and had achieved impressive results. Dr. Adam Arkin of Berkeley, the Principal Investigator (PI), explained that CUBES addresses self-manufacturing of astronaut needs through biology. Plants will produce food and nutrition, as well as edible pharmaceuticals. The plant systems are all editable via their genomes. The project's four divisions form a systems engineering group. The key elements are ISRU, incident sunlight, and human and mission wastes. The Year 1 goal was to design each technology and build the outputs, with Year 2 being for testing. Year 3 emphasizes integration, Year 4 is for learning and analysis, and Year 5 will see the team build, test and demonstrate the end-to-end functionality.

Dr. Arkin reviewed key findings. The Microbial Media and Feedstocks Division (MMFD) will harness in situ resources, which it will decontaminate and enrich, transforming them into usable form. Dr. Arkin gave an example of how light and CO2 can be used in this system. There are lots of challenges, like light levels and bands. The engineering will involve manipulating the materials to take advantage of existing light. The team has worked to change the parameters in order to demonstrate the capacity to increase the efficiency of the system. As an example, Dr. Arkin described how best to develop a sustainable system on Mars, which has only a tiny fraction of Earth's nitrogen levels. MMFD has worked to evolve enzymes to grow with the least amount of nitrogen possible. This demonstrates the ability to evolve the base organism to be more efficient. The Biofuel and Biomaterial Manufacturing Division (BBMD) focuses on plastics and their development. Dr. Arkin described how to increase CO2 to make a better substance for printing and showed 3D printer evaluations, along with some of the failures that have led to re-engineering. An effort with lactone led to a cheap and efficient polymer that can be created quickly.

The Food and Pharmaceutical Synthesis Division (FPSD) has developed a solar plant lighting system. Dr. Arkin noted the photobiological optimization of wavelengths for plant growths. A recent discovery is that some plants will grow just as well under a far-red light as under full-spectrum light. This increases efficiency, though not all plants respond the same, as demonstrated by testing of various crops. For example, wheat does not respond at all. The current focus is on lettuce, rice and potatoes. The dwarf rice test demonstrated increased plant density and improved photosynthetic efficiency. Another finding has been that these conditions introduce some stressors due to the dry environment, regardless of the level of watering. The goal is to construct a plant community that can survive in these environments. One approach is to breed increasingly strong plants over time, and the second approach is to measure the dynamics and recomposite the groups by hand.

The FPSD team can engineer lettuce to express a specific bone generation biologic at all times. It is also possible to shoot the DNA into the plant, which will then have the drug going forward, so that the plant manufactures the drug. The latter method is more efficient. The team is trying to produce precise doses now, while working on the stable transgenic. The cyanobacterial metabolic engineering for small molecule drugs involves spirulina, which is easy to test in moving toward a small format reactor. This effort seeks to introduce two genes for acetaminophen production, while also making the spirulina taste better.

Everything involves a reactor and waste products, creating the need to ensure the timely yield of the organisms and locate the levers to optimize yield and efficiency. This falls to the Systems Design and Integration Division (SDID), which is using strict open architecture criteria. Dr. Arkin showed the model architecture, which involves mission specification models, process models, and climate/environment models. Each reactor has to be calculated for optimization. The process model calls for multi-physics modeling, as shown by acetate production in a bioinorganic reactor at Jezero Crater.

The CUBES infrastructure can support this effort to feed into an integrated picture. Mr. Reuter asked whether the drugs were produced individually, assuming a goal of producing a variety. Dr. Arkin replied that a lot can be done via the injections. The current barrier is that the organism can be recalcitrant in bio-engineering, so there is now a tool that will map all the key points that will be involved in creation of a human drug. The elements must all be available, but they can be dried out and stored on paper.

Mr. Reuter asked where potatoes fall on the far-red light testing. Dr. Arkin said that he was not sure, but he expects them to do well. The goal is to produce both better plants and better growing conditions. He described a putative Mars simulation with very low temperatures, noting that it was difficult to achieve Mars pressure. The idea is to get the reactor to optimize the process.

Discussion and Recommendations
Mr. Oschmann began discussion with a focus on what remained unsettled from the previous meeting. Dr. Ballhaus cited the finding about the proposed demise of STMD, noting that things had changed but suggesting the slide from his NAC presentation as a point of departure. That slide said that it is important for any reorganization be done with care not to recreate mistakes of the past, and that NASA should have mechanism to ensure that. Mr. Oschmann said that in light of subsequent developments, he would reword the "proposed demise of STMD" to "options under consideration." Mr. Reuter explained that the focus is to try to understand how NASA's internal organization will best move the Agency's return to the Moon without major disruption. Dr. Ballhaus said that some of the mission-focused options would provide the urgency argument that has been lacking. The emphasis should be on the need to develop the technologies to an acceptable level, while also having mechanisms in place to prevent both the killing of "seed corn" and the disintegration of renewed university connections. Mr. Reuter noted that the urgency arguments now have strength due to being direct pulls.

Acting Associate Administrator Steve Jurczyk would be giving an update to the full NAC the next day before Mr. Bridenstine addressed the all-hands meeting. It was agreed that TI&E did not want to be inconsistent with what Mr. Jurczyk said. Mr. Green thought he would probably review the three options, noting the NAC recommendation given to the Administrator. Dr. Ballhaus added that the NAC used a lot of the TI&E material. In addition, Mr. Bridenstine concurs and the recommendation is being addressed. The NAC communicated this clearly. Dr. Ballhaus thought they might have to wait. Instead, he suggested putting up the NAC recommendation as a reminder. Mr. Oschmann agreed that that would be a better starting point. He did want the three options as a back-up slide for his presentation to the NAC; Mr. Reuter said he could consolidate them onto one chart.

Mr. Oschmann asked for a slide showing STMD infusion for the current goals; Dr. Howell pointed out that STMD began some of those activities years ago. Mr. Oschmann specified power propulsion, heat shield work, and others, while Mr. Johns observed that each of the day's presentations addressed technology infusion. Dr. Ballhaus added that he always tries to note that the TI&E charge is to address technology across all of NASA. Mr. Oschmann said that with the current political push, he wanted to show specific examples of how technology feeds into those goals. There are broad technologies that will have future application, and TI&E can show how STMD supports the current thrust, plus the seed corn that enables it to address the pulls. Dr. Howell noted that those technologies are necessary regardless of which organizational option is selected. Mr. Oschmann explained that the Administrator wanted to see the value of what STMD is doing specifically for the return to the Moon. Using the exploration campaign slide from Mr. Reuter's presentation, he wanted to show which STMD solution best serves these missions.

Dr. Weber said that there are some technologies NASA invested in that are now proving essential, and had those development budgets been cut, the Agency would not be able to move ahead on some of this. The CFM demonstration was eliminated due to budget constraints, for instance. If TI&E wanted to argue to continue investing in these technologies, an example of how cutting the budget has led to a setback might be appropriate. There might be impact in showing the ramifications of not being careful and investing in these technologies. She recommended describing how NASA is not as far along as it might have been had the funding supported more technology work. Mr. Oschmann agreed, though he did not think CFM was the best example. Mr. Johns cited a chart of the TDMs, which were then cut. Dr. Weber agreed that they would be a better example.

Mr. Oschmann said that another point was that some things went away completely. Dr. Ballhaus said that NASA is in the same position it was 30 years ago, then gave some history. There is a need to find a way to do these things affordably. Mr. William Gerstenmaier, HEOMD Associate Administrator, understands that, which is why he advocates doing this in manageable stages. The question then becomes how to develop more affordable technologies. Dr. Weber said that the Administrator wants to see how technology development feeds into going to the Moon. That was the thinking behind having an example of how going to the Moon is hindered by a technology that was not funded due to budget pressure on STMD. Mr. Oschmann cautioned against too much detail on that. He would mention urgency and how it would be good to have a given technology ready instead of having to initiate work on it.

Dr. Ballhaus thought they needed a plan that pulls the technology with clear milestones of what must be available when. However, he was not seeing that. Mr. Oschmann said that the exploration campaign slide would have dates that can be the basis of the urgency and funding arguments. Dr. Ballhaus maintained that the urgency argument requires a major program, but Mr. Oschmann thought there was a conceptual pull in the chart. Regardless, they were not going to get a complete plan so quickly, so he wanted to use what they had. Mr. Green assured the Committee that the chart could have some additions supporting these points, and suggested having bullets to the side about being unable to complete the CFM work due to budget constraints, noting that CFM will be needed. Mr. Oschmann said that they could show the connections. As the detailed plans for return to the Moon evolve, NASA will need a better top-down and bottom-up look to enable future technology planning. Investment is needed to meet the notional schedule.

Mr. Oschmann sought to have slides addressing the exploration campaign, technology programs that have or could feed into it, a specific pull from missions, and the need for a healthy set of new seed corn technologies to prepare for the future missions that have not yet been determined. He wanted to make the point that development of a lot of these technologies began before the return to the Moon was envisioned. He wanted to end by reiterating the previous recommendation, with some modification. Dr. Howell emphasized the importance of stating that NASA had just recovered the university technology programs, and human capital is critical for the Moon and beyond. Regarding the three options, Mr. Oschmann preferred to state the need to protect against past mistakes. That would be done in part by highlighting how well STMD and other programs have worked.

Mr. Green reviewed the three options. Option 1 was to restructure STMD and HEOMD. Option 2 was to create a “super-HEOMD.” Option 3 was to modify STMD somewhat. Dr. Weber wanted to specify that there would be a separate division on exploration technology. Mr. Reuter explained that each of the first two options had an entity on technology, but not at the mission directorate level. Dr. Weber said that the risk is how to define future technology. Leaving that up to HEOMD would put the funds at risk. Mr. Reuter added that HEOMD’s focus is near-term. Dr. Ballhaus suggested checking with the chair of the Human Exploration and Operations Committee (HEOC) to avoid contradicting each other.

Mr. Green reviewed the format of the usual TI&E presentation to the NAC, and the Committee began to organize the charts, pulling out at least one from each of the presentations in addition to the cover charts, and erring on the side of having too many so that they could edit later. The charts from Dr. Tu’s presentation addressed the core competencies at Ames, and the partnerships. The core slide from Mr. Reuter was the exploration campaign chart, which would be expanded. The last chart was added as well. From Dr. Fong’s presentation, the first draft included slides 21-23, addressing future autonomy R&D, and activities by internal and external entities.

Several of the SEP presentation slides were pulled, with the intent of thinning them out. For the OCT presentation, the Committee eventually settled on using the slide that emphasized the partnerships and cited coordination with industry and other government agencies, as well as the fifth slide that listed the studies. On the IRMA presentation, it was decided to modify the summary chart with information for each of the projects, and add some pictures, noting that there is good progress in the competitions. Finally, some of the CUBES presentation slides were to be reworked offline to enhance readability. Mr. Green advised adding verbiage on why technology is important for lunar exploration. Mr. Oschmann said that there are already STMD technologies affecting every mission on the exploration chart. It was suggested that the statement be that technology plays a vital role in returning humans to the Moon and on to Mars, and past and current investments support that. Mr. Reuter said that STMD is in sync with HEOMD on this. Mr. David Neyland suggested a statement about the vital role of technology, with bullets listing STMD investments. Then the last chart would be the message that the Committee put forward last time. The pivot point is to stand by what was said previously about protecting technology investments. He suggested using the words from the letter, not the slide, and including the NAC and NASA responses. Mr. Green said they could take a screen shot of the whole thing, then put the recommendation and responses off to the side. Mr. Oschmann wanted to include the consequences statement. Dr. Ballhaus said that NAC usually has the responses. Mr. Neyland advised stating that TI&E stands by its previous recommendation, and others agreed with this approach.

Once editing began, the Committee removed the technology definition and technology budget challenges, and decided to thank Ames for the tour but otherwise remove the slides. The slides from Dr. Fong's presentations generated a lot of discussion, but ultimately TI&E decided to use only the slide on where NASA can use autonomy. On SEP, Mr. Oschmann planned to praise the project's progress, and focus on the partnership message from the OCT presentation. Regarding IRMA, Mr. Green planned to pull out the highlights. The Committee agreed to stay with the previously discussed summary of the CUBES presentation. The summary was to frame the role of technology around lunar exploration, then repeat the recommendation and the NASA response, stating that TI&E stands by their concerns and the NAC's recommendation.

Adjournment

The meeting was adjourned at 6:16 p.m.

APPENDIX A

Agenda

NAC Technology, Innovation and Engineering Committee Meeting
August 28, 2018
NASA Ames Research Center
Moffett Field, CA

August 28 – FACA Open 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.	Welcome to NASA Ames Research Center (ARC) Dr. Eugene Tu, Director, ARC
8:30 a.m.	Space Technology Mission Directorate (STMD) Update and Discussion Mr. James Reuter, Associate Administrator (Acting), STMD
9:30 a.m.	Autonomous Systems Capability Overview Dr. Terry Fong, Autonomous Systems Capability Leader, ARC
10:15 a.m.	Break
10:30 a.m.	Solar Electric Propulsion (SEP) Update Mr. Todd Tofil, SEP Project Manager, Glenn Research Center
11:15 a.m.	Office of the Chief Technologist Update Dr. Douglas Terrier, Chief Technologist
12:00 p.m.	Lunch
1:00 p.m.	Annual Ethics Training Briefing Mr. Tom Berndt, Chief Counsel, ARC
2:00 p.m.	In-Space Robotic Manufacturing and Assembly (IRMA) Projects Update Mr. Charles Adams, Technology Demonstration Missions (TDM) IRMA Mission Manager, Marshall Space Flight Center (MSFC) Mr. Lawrence Huebner, TDM Project Lead, MSFC

3:00 p.m.	Center for the Utilization of Biological Engineering for Space (CUBES) Update Dr. John Hogan, COR, ARC Dr. Adam Arkin, PI, University of California-Berkley
3:45 p.m.	Discussion and Recommendations
5:00 p.m.	Adjournment

APPENDIX B

Committee Membership

Dr. William Ballhaus, *Chair*
Mr. G. Michael Green, *Executive Secretary*
Mr. Gordon Eichhorst, Aperios Partners, LLC
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:
Jim Oschmann, *Acting Chair*
G. Michael Green, *Executive Secretary*
William Ballhaus, Jr. (via teleconference)
Kathleen C. Howell
Michael Johns
David Neyland
Mary Ellen Weber

NASA Attendees:
Thomas Berndt
Terry Fong
John Hogan
Trudi Kortes
James Reuter, *STMD Acting Associate Administrator*
Douglas Terrier
Todd Tofil
Stephanie Yeldell

Other Attendees:
Amy Reis, Electrosoft
Elizabeth Sheley, Electrosoft

WebEx:
Charlie Adams
Eric Anderson
Gina Anderson
Adam Arkin
Heather Bloemhard
Laurie Chappell
A.C. Charania
Stephen Clark
Shaun Daly
Anyah Dembling
Eric Harloff
Lawrence Huebner
Benjamin Jenett
Ben Kallen
Linda Karanian
Aaron Kiesler
Christopher Lam
Tiffani Long
Jon Neff
Atif Qureshi
Clare Skelly
David Steitz
Bruce Wiegman
Kenneth Wright

APPENDIX D

Presentations

1) Welcome to ARC [Tu]
2) Exploration Research and Technology (ER&T) [Reuter]
3) Autonomous Systems: NASA Capability Overview [Fong]
4) Solar Electric Propulsion Project [Tofil]
5) Office of the Chief Technologist Update [Terrier]
6) In Space Robotic Manufacturing and Assembly Update [Adams]
7) CUBES [Arkin]