National Aeronautics and Space Administration

Technology, Innovation & Engineering Committee
of the
NASA Advisory Council

National Institute of Aerospace
Hampton, Virginia
July 25, 2017

Meeting Minutes

G. Michael Green, Executive Secretary	**William F. Ballhaus, Jr., Chair**

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Open Meeting

Welcome and Overview of Agenda/Logistics
Mr. G. Michael Green, Executive Secretary of the NASA Advisory Council (NAC) Technology, Innovation and Engineering (TI&E) Committee, welcomed the members and reviewed the meeting agenda.

Opening Remarks
Dr. William Ballhaus, TI&E Chair, asked the Committee members for observations he could share with the NAC. He noted that the Space Technology Mission Directorate (STMD) was established to rebuild NASA's cross-cutting technology program, then listed STMD accomplishments and gave examples of future initiatives. STMD has re-engaged the academic community and formed effective partnerships.

Welcome to Langley Research Center (LaRC)
Mr. David Dress, LaRC Space Technology Projects Office Deputy Director, welcomed the Committee and noted that Langley is celebrating its 100th anniversary this year. LaRC's Fiscal Year 2017 (FY17) budget is $922 million, and the workforce of 3,400 is almost evenly split between civil servants and contractors. Langley serves all of NASA's mission directorates in order to develop and deliver mission-enabling space technologies. Emphasis is in five thrust areas: entry, descent, and landing (EDL); space habitation systems; lightweight and affordable space transportation systems; in-space assembly, construction, and operations; and exploration architectures. The value proposition is in taking low- to mid-Technology Readiness Level (TRL) technologies to infusion, though LaRC work extends from concepts through to mission management.

Mr. Dress mapped the thrust areas to NASA's exploration roadmap and gave examples from each area. Among the examples were the Hypersonic Inflatable Aerodynamic Decelerator (HIAD), in-space assembly, radiation impact mitigation using a flexible habitation system, materials work, and structures that will bring down both costs and mass considerably.

Dr. Ballhaus thanked Mr. Dress and noted that Langley has the source of tremendous talent and innovation. He wondered if there were any "superstars" at the Center now. Mr. Dress said that is not the context in which they think. Langley is still known for innovation. Dr. Ballhaus next asked if the scope of work has reduced as the number of civil servants has come down. Mr. Dress replied that the focus has narrowed. Langley is still a source of mission analysis and is getting increased visibility and use throughout the Agency.

Dr. Ballhaus said that he hopes that NASA understands that to be a smart buyer, one needs to have been a doer. Mr. Dress explained that LaRC is good at getting early career people into positions of responsibility with hands-on experience. Dr. Ballhaus noted that TI&E advised the Jet Propulsion Lab (JPL) director to put young people on large teams to learn the system and processes early on.

Space Technology Mission Directorate Update
Mr. Stephen Jurczyk, STMD Associate Administrator, began the status update by listing the Directorate's six strategic thrust areas. The sixth, to grow and utilize the U.S. industrial and academic base, is the most recently added and reflects areas such as the Small Business Innovation Research (SBIR) program. A graphic of the space technology pipeline showed how technologies are matured from low TRLs to high TRLs and through to infusion pathways. Commercial partnerships are involved along the way.

Mr. Jurczyk then presented FY17 accomplishments by thrust area. There were many examples in the first thrust area, expanded use of near-Earth space, including the Laser Communication Relay Demonstration (LRCD), composite cryogenic tanks, and other composite work. Some of the small missions in this area, like CubeSats, have been a challenge due to insufficient launch opportunities. The second thrust area, to develop efficient and safe transportation through space, included projects such as the Green Propellant Infusion Mission that is readying for launch, continued work on Solar Electric Propulsion (SEP), and maturing technologies for small satellite thrusters. For increasing access to planetary surfaces, STMD flight-tested a conformal ablative thermal protection system, the HIAD.

The fourth thrust area is to enable humans to live and explore on planetary surfaces. To that end, STMD demonstrated a humanoid robot with cognitive abilities, awarded contracts for spacecraft oxygen recovery, and delivered hardware for nuclear testing in the area of kilopower. To enable the next generation of science missions, STMD raised the coronagraph being prepared for an astrophysics mission to TRL5, which will increase measuring capacity by a factor of at least 100 over existing technologies. STMD also leveraged the Neutron star Interior Composition Explorer (NICER) mission for pulsar timing experiments.

Finally, in the thrust area for technology transfer, STMD infused its materials work into a fire shelter for the U.S. Forest Service, high power solar arrays were transitioned to industry, and more. STMD has partnered with over 380 companies among almost 600 entities altogether. An example is the Tipping Point Technologies program, which requires industry to invest at least 25 percent of the costs, though the actual proportion is sometimes closer to 40 percent. Mr. Jurczyk also described an announcement of collaborative opportunity that resulted in 13 awards to industry partners for 2016.

Congress had not yet approved the FY17 operating budget plan, though that was expected to occur despite the need for some adjustments. The FY18 President's Budget Request (PBR) made a big change in the robotic satellite servicing area, Restore-L, which is being restructured to a ground demonstration. There is a slight increase in the early stage portfolio, reflecting the Space Technology Research Institutes (STRIs) discussed at the previous TI&E meeting. One of these is studying food growth, and the other is investigating reinforced carbon fibers.

FY18-19 program highlights included the completion of the propulsion subsystem on the SEP, with a May 2019 launch date. The Laser Communications Relay Demonstration (LCRD) will launch in June 2019. The kilopower test will occur in January 2018, and nuclear thermal propulsion will be reviewed in September 2018 with a decision point to follow. Mr. Jurczyk listed elements of the technology demonstration formulation plan, including high-mass EDL technologies, propellant storage and transfer, the coronagraph, and more.

Habitation Capability Development – Human Exploration and Operations Mission Directorate (HEOMD) Technology Development Efforts

Mr. Jason Crusan, Director of Advanced Exploration Systems (AES) for HEOMD, said that HEOMD's goal is to expand human presence deeper into space. At the moment, the International Space Station (ISS) is the platform AES uses to advance exploration technologies. However, it will not be sufficient for deep space. In the 2020s, the program hopes to operate in the lunar vicinity as a proving ground, then go to Mars orbit after 2030. Mr. Crusan presented eight strategic principles for sustainable exploration. The Orion crew vehicle and the Space Launch System (SLS) are in development now.

In Phase 1, the Deep Space Gateway (DSG) will have a power element, habitation element, logistics element, and airlock, each of which will be transported on separate SLS flights. The Gateway will be capable of supporting a crew of four for up to 42 days; it will not be as complex as ISS. Mr. Crusan presented the Phase 1 plan, starting with EM-1, an uncrewed SLS flight of up to 40 days on a Distant Retrograde Orbit (DRO). By the fifth flight, EM-4, there would be the capacity to stage for cis-lunar flights. Dr. Mary Ellen Weber asked if the EM-2 flight, which will include a crew, would use Orion to configure the power/propulsion element. Mr. Crusan said that it will be more of a free return around the moon. The power/propulsion element does not require interaction, as it is a self-staged deployment.

Phase 2 will focus on the DSG and the Deep Space Transport (DST). Mr. Crusan showed the transport delivery plan, in which EM-6 will send up the DST. This flight will not carry a full load of fuel in order to manage the mass. The logistics will be sent from EM-7 through EM-11. The goal is to have a crew of four in deep space for 1,000 days. Another objective is reuse of transportation elements. AES hopes to have a shakedown cruise by 2029.

In the habitation area, current work in Phase 1 involves developing concepts and prototypes with international and industry partners. This will determine which parts of the DSG should be supplied by the government, and these decisions should be made by the end of 2018. The prototypes will be full-scale, as there are many options for demonstrating habitation systems. There are six domestic studies and one international effort, and AES expects to learn from all seven. The Next Space Technologies for Exploration Partnerships (NextSTEP) Phase 1 is complete, and the partners are now refining concepts and developing prototypes for Phase 2. Mr. Crusan described some of the approaches to implementing habitats. Some industry partners leverage existing systems, for example, while others start from scratch. NASA does not provide a lot of guidance in this area because the Agency wants to explore different concepts.

The specific deep space habitation systems objectives address life support, environmental monitoring, crew health, radiation protection, fire safety, logistics, and cross-cutting issues. Mr. Crusan showed a graphic of the current state for each of these alongside the needs for deep space. ISS is testing various elements to the extent possible, and JPL is providing the environmental monitoring/life support work. Astronauts in deep space will need different exercise equipment from what is used on ISS. In addition, ISS is demonstrating radiation sensors, fire safety, and logistics. These efforts illustrate the challenges in the various disciplines. There are roadmaps in each of these seven areas, and AES has looked at how they feed into each other for a regenerative life support system, as well as how to fully integrate them. A full-scale module on ISS tested materials and other elements.

The Spacecraft Fire Safety Experiments (Saffire) project is testing a fire risk reduction system over a series of six flights. The first three showed that large-scale fires behave differently than small-scale fires. The remaining three flights will focus on detection, suppression, and cleanup. In the area of radiation detection and mitigation, there are sensors being tested on ISS and others being prepared to go on Orion. The Radiation Assessment Detector (RAD) is operating on the Mars Curiosity Rover. Tiny sensor chips that came out of CERN, called Radiation Environment Monitors (REMs), are now inside ISS, where crews have made them using 3-D printing. The REM shields are part of an investigation of shielding options, and they also help radiation characterization. The Hybrid Electronic Radiation Assessor (HERA) detects radiation levels and will fly on EM-1 and -2.

In-space manufacturing will be another key to deep space. Studies are now looking at how often a material can be reused/repurposed before it degrades to the point of inoperability. Dr. Weber said that the need for spare parts and the associated logistics have constituted a limitation. She asked about work that might address that barrier. Mr. Crusan said that about half of the deep space effort is in logistics, with most of the rest being usability. Specific work involves such areas as reliability, closed-loop water, and CO2 recovery. Advanced manufacturing is looking at all ISS failures and possible prevention strategies. There are multiple bionutrient issues related to biomanufacturing, such as long-term nutrient stability. NASA is working with the Food and Drug Administration (FDA) to develop amino acids that can be stored and hydrated for consumption. There is significant private sector interest in this area. There are many investments in In Situ Resource Utilization (ISRU). Mr. Crusan gave a number of examples, including extraction of volatiles or consumables from extraterrestrial atmospheres.

Thirteen CubeSats have been selected to fly on EM-1 as secondary payloads that will advance technologies. Mr. Crusan showed a crosswalk of CubeSats, the technologies advanced, and the strategic knowledge gaps addressed. CubeSats are extremely cost-effective in getting the environmental measures needed before sending humans on a mission. South Korea announced the Korea Pathfinder Lunar Orbiter (KPLO), on which NASA is a partner. It uses the same camera as that on the Lunar Reconnaissance Orbiter (LRO). The Resource Prospector technology will characterize water and volatiles in the lunar polar sub-surface materials and demonstrate ISRU processing of the lunar regolith.

Mr. James Oschmann said that there has been talk about testing and possible assembly of telescopes in L2 and the lunar area. Mr. Crusan confirmed that servicing telescopes is a goal. There are many payloads on the ISS, and NASA envisions the same model for the Gateway. DST could even drop off payloads.

Centennial Challenges Program Findings and Response

Mr. Jim Reuter, STMD Deputy Associate Administrator, explained that the objective of the Centennial Challenges (CC) program is to stimulate innovation with potential for application of NASA's space and aeronautical activities. It is not necessarily technology infusion. An independent review was set up in late 2016 to evaluate the CC portfolio. The team developed 17 findings, and STMD concurs with all of them.

Mr. Reuter reviewed the CC history and past challenges. Some challenges expired with no awards given. Active challenges include Cube Quest (funded for $5 million), Space Robotics ($2.5 million), 3-D Printed Habitat ($2.6 million), and Vascular Tissue (VT - $0.5 million). One more competition was planned for FY17. It is hard to construct a challenge that consumes all of the funds without making the challenge too easy. CC considers 60 to 70 percent to be a good target for prize money awarded. Unspent funds go back into the prize pool. Aside from VT, which provides the funds up front, most challenges seem to work better with incremental awards, which are narrowed down along the way. The prize money is only for accomplishments, and the awardees must fund their milestones themselves. They often use awards to move ahead to the next milestone. The awardees are quite diverse, ranging from an individual working from home to teams in academia and industry.

Mr. Reuter next reviewed the 17 findings of the Independent Review. (Finding 12 was a duplicate.)

- CC concurred with Findings 1 and 14.
- CC will leverage resources in response to Finding 2.
- For Finding 3, CC removed "infusion into NASA missions" and returned to technology transition plans. The goal is to see what can guide future investment.
- Finding 4 stated that the roles lack clear definition, which STMD will address, noting that this needs a lot of work.
- CC is already implementing Findings 5 and 18.
- Finding 6 advised considering larger awards to deal with the unspent funds. CC is looking at this. It was noted that most competitions have been designed in phases.
- CC is discussing Finding 7, to eliminate or reduce registration fees, with allied organizations.
- CC will address Finding 8, to identify exit strategies for challenges that do not work.
- Finding 9 advises capturing data on the time it takes to go from challenge idea to competition. CC is reviewing the process and will update it as needed.
- CC concurs with Finding 10, which cites the need for a robust process for external input, and will work to improve it.
- Finding 11 addresses the roles of allied organizations; CC will review this to ensure that NASA maintains control.
- Finding 13 recommends clarifying the decision-making authority; CC explains how this is done.
- CC will follow the advice in Findings 15 and 16.
- CC concurs with Finding 17 and will continue working on it.

Dr. Ballhaus praised the effort and added that the CC method of infusing technology is unique. Mr. Reuter said that for areas in which NASA wants to capture more ideas, the program can bring in new audiences. Mr. Jurczyk added that some of the technology prototypes from CC have rolled into standard technology projects. This also gives STMD a look at what is possible and may show promise. Something that does show promise would be pulled into the Game Changing Development technology portfolio.

Dr. Ballhaus said it would be helpful for TI&E to get a one-chart summary of the infusion successes that could be communicated to others. Mr. Jurczyk agreed, noting that this mapped to one of the recommendations. Mr. Michael Johns asked if the Army or any other agencies do prize challenges like this, and if so, whether they might be linked. Mr. Reuter replied that other agencies do have such challenges, citing NIH as an example. Mr. Jurczyk added that CC has a unique set-up with funds that never expire but cannot be reallocated elsewhere. Other agencies can contribute to the prize money or the execution of the challenge. Mr. Reuter elaborated, saying that once a challenge is complete, CC can redistribute remaining funds to other challenges. The program does not receive funding every year, but instead asks for it in order to start new challenges.

Chief Engineer Update

Ms. Dawn Schaible, NASA Deputy Chief Engineer, discussed capability leadership, which helps NASA ensure alignment across missions and centers. The Office of the Chief Engineer (OCE) manages 19 discipline capability areas. Other capability areas across NASA cover service, systems, research and portfolios; these are managed elsewhere in the Agency. The OCE model assessment process starts with a baseline that involves understanding the needs, capabilities, and challenges at the centers. The baseline is repeated every three years, and there is an annual summary that looks at the state of each capability.

Ms. Schaible reviewed the FY16 Technical Capability Assessment results. The teams put forward 123 recommendations, which were winnowed down to nine specific recommendations for Agency consideration. The first was a strategic theme of making it easier for the workforce to share resources, and has resulted in a mechanism for discussing priorities. Another recommendation addressed funding for engineering research and analysis (R&A). The Agency is developing tools to address this for FY19. This investment would be more focused and better-integrated than the current diffuse funding. Mr. Jurczyk added that the teams are identifying the gaps and STMD is committed to allocating additional resources. It has been challenging.

Ms. Schaible explained that the third and fourth recommendations had to do with facilities, and Mr. Ralph Roe, the Chief Engineer, is studying options. Fifth is a software recommendation permeating all activities. A first step is to reuse the software that NASA already has. The Agency has also started making it easier to share internal software. Recommendations 6 and 7 address system engineering and are in process. The last two recommendations, 8 and 9, spoke to how NASA does capability leadership and the capabilities themselves. This has resulted in transitioning some capabilities to the mission directorates that have most direct responsibility, while also working with the disciplines. The cadence of these reviews will change so that the baselines are rewritten every 6-7 years. OCE is asking each capability leader to identify where the capabilities need to go over the next 5 years. OCE has the ability for the capability teams to bring things forward regardless of cadence. There is a 3-year rotation to baseline all 19 capabilities.

Mr. Roe added that this has been the busiest time since he joined the Agency, so this work is essential in order to develop the more efficient operating models that are necessary. Dr. Ballhaus observed that OCE is a functional organization, which means it has four responsibilities: personnel, work/process construct, tools, and checks and balances. He advised thinking of how OCE adds value to each of those four areas. The capability leadership should have a strong demand from the mission directorates. It is not clear the extent to which the engineering organizations can use leverage for cost reductions. Standardized tools, processes, and systems enable movement of capabilities. An engineering organization could play a strong role in this kind of thing. Mr. Roe replied that OCE does not have responsibility for all of the functional areas, but he does have the check-and-balance function for engineering. There is a construct that covers the four areas Dr. Ballhaus mentioned. The capability leaders have identified in each discipline those areas in which excess tools and methods need to be reduced. The result has been a set of best practices and guidelines. Regarding checks and balances, OCE can react to any Agency request from a senior leader. OCE does 50-60 technology assessments per year.

Mr. Johns asked about having a hypersonics technology area, which has significant funding at the Department of Defense (DOD) and might be leveraged. Mr. Roe said that this is in aerospace science, and the Agency is in discussions with DOD on how to advance.

Advanced Manufacturing and Structures Update

Dr. Keith Belvin, LaRC Principal Technologist, explained that structures touch everything. An area of particular interest is lightweight materials. The technology goals are challenging, with ambitious reductions in cost and mass compared to the current state of the art. The impact goals are accelerating adoption and increasing the payload to Mars. There are four key areas of work. First is human-rated composite structures, with a 30 percent mass reduction in EDL achieved already. Next is in-space manufacturing (ISM) and in-space assembly (ISA) of large-scale structures. Congress is now requiring serviceability, which would also enable and require ISA. The third key area is advanced materials systems, including deployable structures and soft structures. The final area was work on materials and structures for extreme environments. Dr. Belvin noted that he was not addressing that area in the rest of his presentation.

For human-rated composites, the challenge is that these are not as mature as metallics, especially for inspection. STMD is trying to develop large-scale validators in order to test and prove these. An example is a composite cryotank technology (CCT), which was demonstrated in 2014. A clean and controlled environment is essential for manufacturing these composites. The Mars ascent vehicle is the big driver in terms of mass. The complicated structures with composites have not been shown to save as much weight as simpler ones, but progress continues in areas such as thin-ply composites. LaRC has been working with composites for about 50 years, especially on the aeronautics side, so they do know the area well. The experience level helps, and it affects the confidence factors from one product to the next.

NASA typically thinks in terms of deploying large objects, but persistent assets are becoming more important. For example, in the ISM/ISA area, NASA could move to platforms and services, then rent the space, which would enable swapping out payloads. For human exploration, it is important to engineer for resilience, not just reliability. ISS is an example, as it was assembled over a period of years. The Hubble Space Telescope (HST) is another example; it is more capable now than when it was launched. Science and exploration need ISM and ISA, because modular assembly helps with affordability and resilience. If the cis-lunar gateway happens, ISM and ISA would allow NASA to build and service the vehicles as needed. Engineering design and technology for resilience is an important issue for DOD as well.

In the advanced functional materials area, NASA has been working with Carbon Nanotube (CNT) powder for many years, as has DOD. There has been a lot of testing of yarns and ultra-lightweight cores, and CNT is close to being as strong as carbon fiber. Optimizing the CNT composite will yield mechanical properties much larger than carbon fiber composites. The Institute for Ultra-Strong Composites by Computational Design (US-COMP) is focusing on four areas: simulation and design, testing and characterization, material synthesis, and material manufacturing. The project involves 27 different universities with the ultimate goal of bringing together the high-strength CNT yarns, core, and ultra-thin ply laminate. There is an urgency to all of the structures and materials work due to the Mars missions, which will need these composites to be matured.

Mr. Oschmann explained that some in the large telescope community are debating these products and are very divided, so that even if STMD makes great progress with composites, the work might not move forward. In addition, those concerned with cis-lunar astronomy are talking about doing assembly in cis-lunar orbit, then moving it out.

Future Technology Demonstration Missions and IRMA Update
Ms. Ginger Flores, STMD's Technology Demonstration Mission (TDM) Program Manager, reviewed the TDM portfolio. Restore-L has budget uncertainty but is moving to Preliminary Design Review (PDR) later in the year. TDM is just starting work on Deep Space Optical Communications (DSOC). Mr. Jurczyk noted which parts of the portfolio are likely to go to flight demonstration. These would include Deep Space Atomic Clock (DSAC) and the Green Propellant Infusion Mission (GPIM), among others.

Ms. Flores said that three IRMA awards were made to public/private partnerships, each for two years plus an option year. All three focus on robotics. The Space Systems Loral (SSL) Dragonfly focuses on the innovative packaging and stowing of large reflectors. The Made in Space (MIS) Archinaut characterizes structures and materials the team has developed. Orbital ATK's Ciras will emphasize the robotic assembly, maintenance, and repair of spacecraft modules. All of the teams are making good progress and appear likely to achieve their requirements. The TDM Program will conduct a technology readiness review next spring. Following site visits, all three teams were recommended for approval of the option year. The Program will seek industry input in order to move forward to a flight demonstration. Mr. Jurczyk added that there is also a multi-agency activity in this area to develop an integrated set of activities that are responsive to industry desires.

Ms. Flores next described the HIAD, a deployable aeroshell consisting of an inflatable structure and a flexible thermal protection system to protect the entry vehicle through hypersonic atmospheric entry. HIAD is meant to address the challenges of decelerating large, heavy payloads on Mars. The technology will enable a greater range of where to land. The goal is to do flight testing in the early 2020s in order to move toward putting humans on Mars in the late 2030s. The flight demonstration also has some strong near-term commercial technology pull.

eCryo has the goal of developing and infusing cryogenic fluid management (CFM) technologies. Ms. Flores described five projects in this area, including a radio frequency mass gauge, integrated vehicle fluids, and others. The eCryo team at NASA's Glenn Research Center (GRC) has developed a large and extensive roadmap, assessing 25 CFM activities and identifying 12 that could move forward. There is a CFM Request for Information (RFI) out to develop a public/private partnership. The RFI lists interest areas such as ISRU-based production systems, nuclear thermal propulsion, and others.

The coronagraph is a direct imaging technology that, should it fly on the Wide Field InfraRed Space Telescope (WFIRST), would provide images unlike any currently available. The combined investment from the Science Mission Directorate (SMD) and STMD has brought the technology to TRL 5. The goal is to bring the technology to TRL 9, enabling breakthroughs. This is a high SMD priority and the highest priority for STMD.

The Kilopower project is an approach for long-duration, sun-independent electric power for space and extraterrestrial surfaces. This is NASA's first attempt to build and test a space reactor since the 1960s, and it has applications for both government and commercial missions. It would be particularly helpful for long-term Mars surface operations involving humans. The systems could also go onto the moon. Plans are to test a 1kw reactor by the end of 2017, then do a scalability study. Dr. Weber asked about the waste product, expressing concern about the safety of the reactors. Mr. Jurczyk said that STMD has not yet gotten to the point of considering waste, but will look at it going forward. Dr. Weber pointed out that they were talking about nuclear waste that would contaminate Mars. This needs to be thought through after the demonstration. Mr. Jurczyk said that they are starting to do mission analysis on the space side. This is not the solution for nuclear/electric propulsion. NASA has just begun talking about what is involved. The current design uses reflectors. He took an action item to present the status at the next TI&E meeting.

STMD Strategic Framework Discussion

Mr. Patrick Murphy, Director of Strategic Planning and Integration for STMD, explained that the STMD Strategic Framework was based on a similar effort by the Aeronautics Research Mission Directorate (ARMD) and used some of that language. The framework describes the technologies that can further NASA's work. Mega-drivers are the overarching trends that largely shape civilian space research. Mr. Jurczyk explained that the focus on civilian work stems from the prior administration's belief that DOD should fund any primary drivers that are defense-related. There has been no change in that guidance and, other than hypersonics, there is nothing in the strategic framework that would be led by DOD. Given the needed funds, STMD would be glad to work with DOD. NASA may have unique capabilities in hypersonics that could apply elsewhere in the Federal government and industry. There are many collaborations between NASA and DOD.

Mr. Murphy said that for the vision of the future of space, the outcomes are the overarching, measurable goals. The technology challenges represent STMD's contributions to achieving the outcomes. There are four mega-drivers. First is increasing access to space, which involves major trends such as reusability and new mission platforms. Another mega-driver is accelerating the pace of discovery for both exploration and science. The third is the democratization of space, which involves broadening investments and participation to other governments, as well as the private sector. The final mega-driver is the growing utilization of space for purposes such as weather applications and GPS. Mr. Murphy explained how the mega-drivers track to STMD's six strategic thrust areas.

Quantifiable Capabilities (QCs) represent the best available quantifiable information to drive portfolio prioritization. Dr. Ballhaus asked about accountability in producing the outcomes.

Mr. Jurczyk explained that STMD is considering which structures will be most useful in achieving the strategy. He holds multiple people accountable for the same outcomes. Dr. Ballhaus noted that many of the advances in commercial space comes from billionaires, who are wild cards. However, NASA needs some assurance that the capabilities will be there in the future. Mr. Murphy said that the mega-drivers are the trend, with or without the billionaires. Mr. Jurczyk described innovations in reusability as an example of a trend that others adopt. Mr. Oschmann said that most startups are likely to fail, but there is still a trend of increasing access to space.

Dr. Weber said that the public now views space as accessible and safe. She wanted to see the risk levels mapped. An underlying mega-driver should be decreasing the risk, which she maintained should be part of the roadmap. She was concerned that most people do not understand how risky this still is. There will be a loss of people in vehicles at some point, and that should be acknowledged. Mr. Oschmann said that they were discussing trends, but he, too, wanted to know the plan to ensure better reliability. Dr. Ballhaus described the statistical trends for launch failure, the likelihood of which declines over time. The highest likelihood of failure is in the first three launches of a vehicle. There is a learning process that they will see with crewed missions, and there is a higher risk at first. The NASA launch people should have a greater responsibility in mission assurance for commercial crew, as NASA has the most experience in this area.

Dr. Kathleen Howell noted that she had same reaction. There seems to be a place in the message for something that is not in the trend but warrants work nonetheless. Mr. David Neyland pointed out that the presentation listed only positive things. He raised the issue of responsible stewardship of space. The proliferation of CubeSats, etc., and the density of space objects also affect safety. This should be considered in the “growing utilization of space” mega-driver. He added that he agreed with Dr. Weber and would add the issue of complacency to her concerns.

Mr. Murphy closed his presentation by showing the path forward, with a development timeline. Mr. Jurczyk said that this should be a subset of what STMD is doing, and part of the Agency strategy as well. Dr. Ballhaus said that it needs a focus on both outcomes and technology. Mr. Green suggested having a follow-up at the next TI&E meeting.

Discussion and Recommendations

Dr. Ballhaus asked the Committee members for their input on the presentation he would be giving to the NAC. Mr. Oschmann said that there was a lot of good information from the meeting, showing progress in a number of areas. The new strategic framework had the most discussion and he looked forward to engaging on that. He thought they should have the message of the safety and risk trend, as well as space debris and stewardship, with a couple of specific examples. Dr. Ballhaus said that the Committee could re-engage in November about how to implement the framework. For some items, the goals are system-level with more than one path. He did not see anything that was actionable.

Dr. Weber said that she found Mr. Crusan’s briefing very enlightening. The independent review of the CC program was another highlight, and it was good to see that the feedback was embraced, as it will bear fruit for the Agency. Mr. Johns also liked the CC review, but he felt that the program does not have enough challenges and is not giving out enough money. They also seem to have a need to engage more with the other mission directorates. Mr.

Jurczyk thought the engagement was fine, but there might be space for additional challenges that could be executed jointly.

Dr. Howell agreed about the framework. As for AES, they have to respond quickly, which they do and which is not easy. Focusing on autonomous capabilities will be difficult, so the earlier they can do that, the better. Mr. Jurczyk agreed. He noted that the Agency is heading toward partially crew-tended systems, which is new. Up to this point, there has not been a blending of humans and robots. Another issue is moving around on Mars, which is difficult and slow. Also difficult is keeping coordination and alignment among the fleet missions. These will be discussed more in the future.

Mr. Neyland thought that the use of the word "civilian" in the framework seemed overly constraining in places. Mr. Jurczyk said that STMD will look at that. Dr. Ballhaus said that NASA first looks at what drives civilian and commercial space, then looks at what DOD does. He thought it was limiting to not leverage the military side. Mr. Jurczyk agreed, noting that he cannot always talk about coordination or connections with the military, but he always wants to leverage where possible. Mr. Neyland also liked the kilopower presentation, and this could be a high-payoff technology. There are not a lot of new or enhanced propulsion systems coming along. Dr. Ballhaus cited Dr. Weber's point about the waste. It is an expensive proposition on Earth, and the options for space remain unknown. Mr. Neyland asked if the CC program review determined why certain challenges were not attractive. Mr. Jurczyk replied that one challenge became increasingly expensive until STMD stopped it. Some were too hard. It also takes time and resources to respond. Not everything the program formulates will move forward.

Dr. Howell asked when the final version of the framework would be done. Mr. Green said that it is part of a larger discussion. Mr. Jurczyk explained that the Principle Technologists will need to conduct workshops. Also, launching anything nuclear would be a challenge that must be addressed. At some point, it might be good to have a joint SMD/STMD session. They could circle back to the small spacecraft technologies, where technology development is focused on some challenging requirements. The technology pull is beyond what anyone would want. An example is two spacecraft flying in precision to create a telescope. STMD wants to focus on what only NASA can or wants to do.

Dr. Ballhaus said he could start his presentation with a finding based on Mr. Murphy's presentation, that STMD is revising its space technology strategic framework. The draft bullet points would be:

- TI&E agrees with the revised strategic framework presented.
    - The Committee suggests two additional considerations for the mega-drivers:
        - Consideration of safety/risk (Increasing Access)
        - Responsible stewardship and debris mitigation (Growing Utilization of Space)
- Outcomes are currently being defined.
- The implementation plan and ownership of outcomes remain to be defined.
- TI&E will re-engage with STMD at the Fall 2017 meeting.

Dr. Ballhaus also wanted to address the independent review of the CC. He had hoped to have a move-the-needle chart showing what has been infused. The presentation charts showed effort, not outcome. He prefers to show NAC the payoffs of investments. Mr. Reuter said that he would provide such a chart. Dr. Ballhaus said that he would then make the following observations:

- The independent review of the CC appears to have been very effective. All findings and recommendations were accepted and are being implemented.
- TI&E endorses the following CC review finding:
    - NASA's mission directorates, in close coordination with the CC, must significantly increase their roles into the crafting of future challenges. Past experience in government and industry indicates that the impact and usefulness of the challenges, even though deemed successful, is highly diminished without such buy-in.

For Mr. Crusan's deep space habitation update, it was agreed to mention both the need to minimize crew interaction, and assembly and materials. Dr. Howell said that the autonomy discussion encompassed multiple presentations, which others agreed was the cross-cutting theme. They would encourage the Agency to leverage that in a recommendation to all four mission directorates. Regarding the TDM presentation, Dr. Ballhaus called up the slide on kilopower. Mr. Jurczyk pointed out that this is not a top STMD investment and ranks fifth or sixth in the queue for TDM. The Committee agreed to hold this.

Dr. Ballhaus identified some milestones, such as the NICER launch, the pending DSAC and GPIM demonstrations, and the upcoming SEP PDR. He selected four FY17 strategic thrust examples, including the coronagraph and DSOC. He also used a few examples from Ms. Schaible's presentation. He would send out the completed slides to the members for comment before the NAC meeting. He added that the presentations were outstanding.

Adjournment
The meeting was adjourned at 5:25 p.m.

APPENDIX A

Agenda

NAC Technology, Innovation and Engineering Committee Meeting
July 25-26, 2017
National Institute of Aerospace (NIA)
100 Exploration Way, Room 101
Hampton, Virginia

July 25, 2017 – FACA Open Meeting

8:00 a.m.	Welcome and Overview of Agenda/Logistics (FACA Session – public meeting) Mr. Mike Green, Executive Secretary
8:05 a.m.	Opening Remarks Dr. William Ballhaus, Chair
8:10 a.m.	Welcome to LaRC remarks Senior LaRC official
8:30 a.m.	Space Technology Mission Directorate Update Mr. Stephen Jurczyk, Associate Administrator, Space Technology Mission Directorate (STMD)
9:30 a.m.	Habitation Capability Development – HEO Tech Development Efforts Mr. Jason Crusan, Director, Advance Exploration Systems, HEO
10:30 a.m.	Break
10:45 a.m.	Centennial Challenges Program Findings and Response Mr. Jim Reuter, Deputy AA, STMD
11:15 a.m.	Chief Engineer Update Mr. Ralph Roe, NASA Chief Engineer
12:00 p.m.	Lunch Break (Box lunch)
12:45 p.m.	Advanced Manufacturing and Structures Update Dr. Keith Belvin, Principal Technologist, LaRC
1:45 p.m.	Future Technology Demonstration Missions and IRMA Update Ms. Ginger Flores, TDM Program Manager, STMD
2:45 p.m.	STMD Strategy Framework Discussion Mr. Patrick Murphy, Director, Strategic Planning and Integration, STMD
3:30 p.m.	Break
3:45 p.m.	Discussion and Recommendations (FACA Open session)

5:00 p.m.	Adjournment

July 26, 2017 - Non- FACA Session

8:00 a.m.	LaRC Tours (non-public)
10:00 a.m.	Coffee/social time for Council and 5 Committees (non-public)
10:30 a.m.	NAC Annual "All Hands" Meeting with Administrator (non-public)

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
Dr. Mary Ellen Weber, Stellar Strategies, LLC

APPENDIX C

Meeting Attendees

Committee Attendees:
William Ballhaus, Jr., *Chair*
G. Michael Green, *Executive Secretary*
Kathleen Howell
Michael Johns
David Neyland
Jim Oschmann
Mary Ellen Weber

NASA Attendees:
Harry Belric
Keith Belvin
Jason Causan
William Cirillo
Vicki Crisp
David Dress
Ginger Flores
Stephen Jurczyk, *STMD Associate Administrator*
Jordan Kloustad
Catherin McLeod
Michelle Munk
Patrick Murphy
Jim Reuter
Dawn Schaible
Ralph Roe
Debi Tomek
Anyah Dembling

Other Attendees:
Amy Reis, Ingenicomm
Elizabeth Sheley, Ingenicomm

APPENDIX D

Presentations

1) STMD Update [Jurczyk]
2) Deep Space Habitation Update [Crusan]
3) Centennial Challenges Program Findings and Response [Reuter]
4) Office of the Chief Engineer Update [Schaible]
5) STMD Technology Strategy: Structures, Materials, & Nanotechnology [Belvin]
6) Technology Demonstration Missions Program [Flores]
7) STMD's New Strategic Framework [Murphy]