NASA AEROSPACE SAFETY ADVISORY PANEL
National Aeronautics and Space Administration
Washington, DC 20546
Dr. Patricia Sanders, Chair

October 16, 2020

Mr. James Bridenstine
Administrator
National Aeronautics and Space Administration
Washington, DC 20546

Dear Mr. Bridenstine:

The Aerospace Safety Advisory Panel (ASAP) held its 2020 Fourth Quarterly Meeting via teleconference September 29-October 1, 2020. We greatly appreciate the participation and support that were received from NASA leadership, the subject matter experts, and the support staff.

The Panel submits the enclosed Minutes resulting from the public meeting for your consideration.

Sincerely,

Patricia Sanders

Patricia Sanders
Chair

Enclosure

AEROSPACE SAFETY ADVISORY PANEL
Public Meeting
October 1, 2020
Conference Call

2020 Fourth Quarterly Meeting Report

Aerospace Safety Advisory Panel (ASAP) Attendees:
Dr. Patricia Sanders, Chair
Lt Gen (Ret) Susan Helms
Mr. Paul Sean Hill
Dr. Sandra Magnus
Dr. Donald McErlean
Rear Admiral (Ret) Chris Murray
Dr. George Nield
Mr. David West
Dr. Richard Williams

ASAP Staff and Support Personnel Attendees:
Ms. Carol Hamilton, NASA ASAP Executive Director
Ms. Lisa Hackley, NASA ASAP Administrative Officer
Ms. Kerry Leeman, Technical Writer/Editor

Telecon Attendees:
See Attachment 1

Opening Remarks

Ms. Carol Hamilton, ASAP Executive Director, called the meeting to order at 11:30 a.m. EDT and welcomed everyone to the ASAP's Fourth Quarterly Meeting of 2020. She indicated that no comments or statements had been submitted prior to the meeting, but time would be allocated at the end for public comments.

Dr. Patricia Sanders, ASAP Chair, opened the meeting by noting that Panel members held intensive virtual discussions with NASA over the course of the Fourth Quarterly meeting of 2020, and during the intervening period since ASAP's Third Quarterly meeting. She indicated that NASA has been engaged in an amazing—perhaps unprecedented—period of activity with multiple events and development efforts, including the re-entry and recovery of the SpaceX Demo-2 Dragon capsule, follow up of the Boeing Orbital Flight Test (OFT) mishaps, several critical extravehicular activities (EVAs) on the International Space Station (ISS), initial steps of the Artemis Green Run (despite the impact of four hurricanes), certification baseline reviews with the Human Landing System (HLS) providers, and much more. These efforts, Dr. Sanders emphasized, were carried out within the environment of a pandemic and the restrictions it imposes.

Part of the Panel's time was directed toward a continued look at the various steps NASA has taken to ensure, as much as possible, the safety of personnel while conducting its vital missions. Dr. Rich Williams addressed those steps and the impact of the restrictions. He also talked to the ASAP's engagement this period on aspects of the effects of space exploration on human physiology.

NASA's COVID-19 Update

The Panel was briefed by Dr. JD Polk, NASA Chief Health and Medical Officer and Dr. Sharmi Watkins, Health and Medical Technical Authority Lead. NASA continues in Phase 3 (the highest phase) of its pandemic risk mitigation posture, with on-site workers limited to mission-essential personnel, and the majority of the workforce in telework mode. Dr. Williams stated that this approach has been successful for the Agency, with viral transmission limited to a few small outbreaks across NASA centers. In the workplace, NASA mandates strict adherence to social distancing and masking, maximizes air exchanges with HEPA filtration, and leverages screening technologies to reduce the risk of viral entry and transmission. NASA employs automated fever kiosks, which screen employees for temperature elevation and COVID symptoms, and is evaluating wearable technology to monitor respiration and pulse rates. Dr. Williams noted that elevation of pulse and respiration rates often precede symptom development, and can aid in detecting asymptomatic transmitters early. The pandemic has impacted most, if not all NASA programs from both cost and schedule perspectives, but a variety of work-arounds have been employed to minimize the effect. NASA is evaluating progression to Phase 2 of its pandemic risk mitigation plan at multiple centers, informed by local community viral transmission levels, which would allow more workers on-site, with telework remaining the primary working mode for those employees able to do so. Dr. Williams was encouraged that NASA senior leadership remains highly visible and intimately involved in the pandemic response on a daily basis, and is firmly committed to practices that will protect the workforce as much as possible.

Human Health and Performance Update

The Panel is very interested in the human health and performance risks attending exploration class missions beyond low-Earth orbit (LEO). Dr. Williams indicated that the Panel appreciates the maturity achieved in the design and implementation of NASA's crew health and performance lifecycle approach. Health and performance risks are understood and mitigated through a human health-related standards-to-requirements flow, in step-wise fashion from biologic research through technology and systems/vehicle design and development to human space flight operations. Evidence is gathered and codified at all steps to inform and further understand the risks, completing the cycle, stated Dr. Williams. Health risks are attributable to five main human system stressors: altered loading; closed environment; radiation; isolation and confinement; and distance from the Earth.

NASA recognizes health and medical system requirements can be difficult for designers and developers to accommodate and meet in human space flight systems. Part of the perennial challenge attending these requirements is a lack of familiarity among developers of the evidence base supporting them, advised Dr. Williams. NASA health and medical authorities have developed tutorials accompanying each health and medical standard and requirement to inform system designers, developers, and operators about the relevant human health risks and

evidence base. Dr. Williams stated that this facilitates better understanding and mitigation of human health risks through all programmatic phases.

From a risk-acceptance perspective, NASA understands exploration class missions will "flip the life/limb paradigm." In LEO, said Dr. Williams, evacuation is a default mitigation step to preserve crew life and limb. In an exploration class mission, evacuation will be delayed or not possible. NASA is working to bring ethical considerations attending exploration class risks and potential consequences to the health and medical policy level. NASA is also engaging in a comprehensive review of health standards, discarding those without a supporting evidence base, and revising all standards with the latest evidence. For example, Dr. Williams indicated, the radiation exposure standard, informed by longitudinal crew health data, may be modified to remove gender discrepancies to become less conservative; this would enable more individual astronaut flight opportunities, and further enable exploration class missions.

The Panel is concerned about potential long-term health effects attending longer duration flight and flight beyond LEO. The Panel understands the occupational health approach to astronaut health, and the option for astronauts who develop health problems to seek remediation through the occupational health program. The Panel would like to hear more about this going forward. Specifically, the ASAP wants to know that NASA has the best opportunity to fully understand the health consequences attending space exploration, and in turn, can ensure adequate and accessible health care for those sent in harm's way. The Panel compliments NASA on its lifecycle approach to crew health and safety, and looks forward to hearing about further evolution as the Agency moves forward.

Commercial Crew Program

Dr. McErlean indicated that the Panel spent a considerable period discussing CCP efforts. In summary, he noted, the Program is currently progressing toward the transition from development/test over to production and delivery of crew transportation services. While both contractors are at different places along that path, both are making tangible progress towards the final goals, stated Dr. McErlean. He then discussed the SpaceX Demo-2 progress.

As the nation looked on, SpaceX launched astronauts Robert Behnken and Douglas Hurley at 3:22 p.m. EDT on Saturday, May 30, 2020. The vehicle docked to the ISS on Sunday, May 31. At 2:48 p.m. EDT Sunday, August 2, the crew splashed down in the Gulf of Mexico off the coast of Pensacola, Florida. Dr. McErlean mentioned that planning and preparations for other CCP missions continue.

SpaceX Crew-1 (a post-certification mission to the ISS with crew) is scheduled to launch October 31, 2020. In December 2020, Boeing OFT-2 is expected to launch, followed by Boeing Crew Flight Test (CFT) to the ISS in June 2021. In late December of 2021, Starliner-1, a post-certification mission to the ISS with crew, is slated to launch.

Dr. McErlean continued to summarize the Program's progress by stating that space hardware manufacturing, testing, and qualification continue. Furthermore, NASA continues to engage the providers as they perform critical test and verification events. Progress continues to be made in the risk burn-down of key certification products with the providers.

Dr. McErlean next discussed how the CCP is adopting a lessons-learned management approach. CCP Program Manager, Mr. Steve Stich, reviewed with the Panel, the Program's utilization of a "lessons-learned" approach to share information from every flight with other NASA programs. Mr. Stich talked about specific information sharing that the CCP undertakes and plans to continue to carry out after each mission, including sharing some information between the principal contractors.

The Panel observed that this approach appeared to provide considerable benefits, and they suggested that the approach be more formalized and distributed as a recommended practice to all NASA programs. Mr. Stich agreed that this approach may have benefits broadly across the Agency.

Although not a main part of the discussion, CCP leaders did mention their effort to potentially secure suborbital services to allow NASA personnel to conduct microgravity research. In June of this year, the CCP issued a request for information to industry to begin the process of determining what capabilities might be of value.

The key issue, Dr. McErlean asserted, is how—and to what extent—the certification of these platforms will be accomplished in order to allow NASA personnel to fly missions. The process for system qualification has not yet been determined, and it is under discussion. In the near future, NASA will host a Webcast with industry to discuss the next steps, and the issue of system qualification.

CCP representatives discussed their current process for risk identification, tracking, and management. The Program has employed an Agency standard process, which has been utilized for many years. This process includes procedures for submitting, reviewing, and accepting or closing identified risks. Decisions are reviewed and accepted/approved via the Certification of Flight Readiness (CoFR) process. However, the Panel observed, and Program leaders agree, that this process will have to evolve as the CCP moves to a commercial transportation steady state. This process is currently being worked by the Program, and various adjustments to the process are being reviewed. The Panel received assurances that NASA will have oversight of production, and will continue to enforce inspection and quality assurance requirements, and that changes will be reviewed prior to every mission. Critical changes will likely require Program Control Board (PCB), and/or higher-level approval, consistent with NASA risk acceptance practice.

Mr. Edward Burns, Manager, NASA CCP Systems Engineering and Integration (SE&I) Office, presented a discussion of the current CCP certification process, and the status of that process with each provider. Dr. McErlean summarized that process.

CCP certification is based on Human Exploration and Operations Mission Directorate (HEOMD) document, HEOMD-CSD-10001, Rev. B, which represents a tailored version of NASA Procedural Requirement (NPR) 8705.2B, Human Rating Requirements for Space Systems. HEOMD-CSD-10001 defines the requirements, standards, and certification package contents that will be used to certify a Commercial Crew Transportation System (CCTS) for LEO missions. The relevant NASA Program Manager and technical authorities determine the applicability of individual requirements and standards based on the Design Reference Mission (DRM) being certified, and apply the Agency risk posture (for the DRM) to arrive at the final set of requirements and

standards for certification. All deviations must be reviewed and approved by the NASA HEOMD Associate Administrator.

Dr. McErlean explained that the Program Manager is responsible for requesting certification from the Agency Program Management Council (APMC). The Human Rating Certification Plan (HRCP) is further defined and codified within the CCP plan. The human rating requirements defined in HEOMD-CSD-10001 are a subset of the total system requirements that must be satisfied by the CCP and the commercial provider to achieve certification of the commercial provider's Crew Transportation System (CTS).

Documentation flow-down, including the explicit documents covering NASA insight, was discussed with the Panel. It was shown to serve as the foundation of the CCP certification process. A provision exists for interim certification in order to support the flight test program, and this was accomplished via formal approval by the Agency. This is necessary, stated Dr. McErlean, as some flight test data is required to complete the validation of compliance to certification requirements. This process is nearing completion for SpaceX, and will be conducted in the same way for Boeing as it reaches the same place in the process. Dr. McErlean indicated that while the above describes the system certification, the crew for each of the missions must also undertake a formal certification/training process.

The Panel observed that while the certification process used by the CCP has apparently been very successful, and it meets the need to formally certify the safety of these systems, it did take considerable effort and time. The total time period to complete the process has been about six to seven years when the necessary test/validation time is included. According to Dr. McErlean, the issue the Program must face now is how to shorten this timeline in order to support future programs. Dr. McErlean called upon Dr. George Nield to further discuss the status of the SpaceX Program.

All operational flight test objectives were met during Demo-2. In terms of the Falcon 9 performance, Dr. Nield stated, it was considered a very clean flight overall. The post-flight data review showed no major findings. For the Crew Dragon, the post-flight data review is complete, and all test flight and mission success objectives were met. Power, mechanisms, propulsion, life support, thermal control, and trailing aerodynamic decelerator hardware systems all performed within expectations. There were a couple of issues identified that have led to some updates that will be incorporated in the upcoming Crew-1 flight. Dr. Nield explained the relevance of these issues.

The first issue, he noted, has to do with the heat shield on the Dragon. The area where the heat shield connects to the trunk section of the spacecraft experienced more erosion than desired. An updated design has been developed and tested in the Arc Jet Chamber at Ames Research Center, and it looks like the modified design will have a significant improvement in its capabilities, said Dr. Nield.

He explained that the second issue had to do with the drogue parachute system, which deployed at a lower altitude than expected, although it did occur within the "allowable box" for reentry. SpaceX is changing the implementation for that, in terms of how GPS altitude is used compared to barometric altitude.

Separately, a number of recreational boaters converged in the Gulf during the Demo-2 Dragon recovery operations. Dr. Nield indicated that NASA has been working with the Coast Guard, the Federal Aviation Administration (FAA), and SpaceX to preclude such a public convergence from happening in the future, through the deployment of additional assets, and by being more clear in the Notices to Mariners that are issued, as well as by making other announcements to the public.

As previously mentioned by Dr. McErlean, the launch of the Crew-1 mission is currently scheduled for October 31, 2020, with an ISS docking planned for November 1. This mission is expected to have a full 180-day duration. This will be the first crewed NASA mission that will be licensed by the FAA. The FAA will be responsible for ensuring that SpaceX meets requirements for public safety for launch and reentry. NASA will be responsible for phases outside of licensed activities, including on-orbit. Dr. Nield stated that sharing responsibilities has worked well for cargo missions to the ISS, and both NASA and the FAA have been working closely together to ensure that everything goes smoothly on the upcoming flight.

Dr. McErlean then summarized spacecraft development status for the Boeing Starliner system. The crew module (CM), service module (SM), and launch vehicle for OFT-2 continues to make progress. The CM is about 80% complete, and the SM about 90% complete. For the launch vehicle, the booster and Centaur have been produced and delivered, and the launch vehicle adaptor is currently in work.

Dr. McErlean next discussed Independent Review Team (IRT) findings related to Boeing's Starliner incident. The 61 recommendations for flight software and mission data loads (MDLs) provided by the Joint NASA/Boeing IRT (JIRT) were prioritized into three categories: Priority 1 – mandatory prior to next flight (27 items); Priority 2 – Highly Recommended (13 items); Priority 3 – Other Recommended (21 items). The Boeing IRT resulted in 31 recommendations, which were grouped into seven different action plans by the Starliner team.

Nineteen recommendations were provided by the JIRT based on the command link outage: Priority 1 – Mandatory prior to next flight (15 items); Priority 2 – Highly Recommended (1 item); and Priority 3 – Other Recommended (3 items).

The Starliner Program has worked closely with the JIRT. Dr. McErlean stated that the team fully understands each recommendation, and is developing actions to address each item. Additionally, the team plans to close the loop with the JIRT to ensure action plans meet the intent of their recommendations. Once JIRT concurrence has been obtained, the action plans are resource-loaded, with completion dates to tie into the overall schedule.

The Panel observed that the processes for resolving and validating these problems continue to be a source of concern as to their progress towards final resolution. Other issues with the Starliner system have been identified during this review process, and mitigation plans are in place to resolve or mitigate these issues as well. Dr. McErlean indicated that it remains to be seen that all issues, including the well-publicized software issues, will be resolved.

Dr. Sanders thanked Drs. McErlean and Nield for their thorough insights. She then noted that for the last decade, NASA has been developing a variety of human spaceflight systems. As the

Agency begins operating those systems, many lessons learned can benefit both ongoing programs and many of the new efforts being initiated for the lunar campaign. The Panel discussed with both the Exploration Systems Development (ESD) and CCP Programs, the criticality of transmitting this information across the Agency. For example, Mr. Steve Stich expressed interest in the idea of deliberately and formally reviewing previous mission anomalies and lessons learned in preparation for follow-on missions, in the same way that NASA has done in their flight readiness reviews for decades. Instituting a formal review process, Dr. Sanders stated, will ensure that the lessons learned, both in development and during operations from the commercial crew providers (i.e., from Boeing to SpaceX), can benefit other Agency programs and future commercial partners.

In addition, the Panel believes that the ESD Program has the same critical need: a formal deliberate process to share and apply lessons learned and anomaly resolutions across the Agency, and in particular, the ESD and Advanced Exploration System (AES) Program boundaries. The imperative to share lessons across program boundaries is not limited to technical issues discovered during development, nor to operational and mission anomalies, but it also pertains to management and organizational experience, explained Dr. Sanders. As the Agency continues to extend the reach of humans beyond LEO, utilizing an increasingly active private sector, and a growing number of developmental and test or operational programs, the Panel advises the Agency to formalize a process that propagates and communicates lessons learned to the Agency and to the broader community in order to minimize the risk of repeating mistakes. Dr. Sanders emphasized that too often, "lessons learned" become "lessons forgotten" as time goes on and personnel change. She reiterated the Panel's belief that there is value to exploring and implementing a more disciplined and proactive forcing function to preclude lessons relearned the hard way.

The next NASA endeavor that the Panel addressed was the ongoing operations on the ISS. Dr. Sanders invited Mr. David West to lead that discussion.

International Space Station

The ASAP regularly tracks the status of the ISS Program. At the Panel's quarterly meetings, through discussions with Program management and key personnel, Panel members learn not only of the amazing accomplishments of the ISS, but also of the significant technical and management challenges that must be overcome. This quarter is no exception, stated Mr. West.

The ISS, he noted, is closing in on a major milestone of nearly 3,000 investigations having been conducted. These investigations have been documented in over 2,000 scientific publications, and they involved work by people from 108 countries.

Station Increment 63 is currently crewed by American astronaut Chris Cassidy and two Russian cosmonauts, Anatoli Ivanishin and Ivan Vagner. Soon, Increment 63 will transition to Increment 64, with these three crewmembers being relieved by two new Russians and a new American. Increment 64 will also see the arrival of the SpaceX Crew-1 mission carrying four new U.S. Operating Segment (USOS) astronauts – three Americans and one Japanese. This will mark the first time that five USOS astronauts will be aboard the ISS at the same time. A significant upgrade planned for Increment 64 is the installation of new solar arrays that will take over for 6 of the 8 arrays currently on Station.

Mr. West stated that mission planning gets particularly challenging with a number of Program constraints, and the relative timing of the SpaceX Crew-1 and Crew-2 missions. Another mission-planning challenge is the fact that some SpaceX hardware from previous launches is being refurbished for future launches. Also, the maximum crew load on ISS is 11 people, due to life support system limits, so the plans for visiting vehicles with crew must be designed to stay within this constraint. Finally, Mr. West explained, to ensure the ISS has at least one USOS crewmember on board, there can be no gap between the departure of Crew-1 and the arrival of Crew-2. He further expressed that a notable event on Increment 64 will be the installation of the Bartolomeo payload on the external surface of the Columbus module. Bartolomeo is a commercial scientific package that is said to represent the European Space Agency's (ESA's) first foray into commercial operations on the ISS.

The Panel was glad to see that the SpaceX-21 cargo mission planned for later this year will include a newly refurbished spacesuit, extravehicular mobility unit (EMU) 3015. This EMU will replace EMU 3008, whose sublimator is nearing the end of its EVA time limit. During this quarterly meeting's discussions with NASA leadership, the Panel learned more information about a concern that has been reported in the news recently—namely, the existence of a small air leak on the ISS. The leak does not currently pose a safety threat to the crew; however, the small size of the leak makes it difficult for the crew to pinpoint its location. In August, teams across the International Partnership formulated a leak isolation plan that involved isolating the crew to the SM, Mini-Research Module 2 (MRM2), and the Soyuz, thus allowing the remaining ISS modules to be ruled out as locations of the leak. While there is not yet a safety concern with this leak, it appears to have exceeded the ISS specification leak rate of 2.3 pounds-mass of air per day, and has begun to involve contingency planning for consumables to be delivered to the ISS. The Panel will be closely following developments with the efforts to locate and repair this leak.

The Panel continues to track the open work status on the planned deorbit strategy for ISS and the fine-tuning of wording in the related Space Station Program document, SSP 51066. The need for this de-orbit strategy was highlighted by the ASAP several years ago, and the Panel will continue to monitor the progress of getting agreement on the strategy by all parties.

Dr. Sanders thanked Mr. West for his summation of the ISS Program. She then stressed the criticality of maintaining U.S. manning of the ISS. NASA continues to work on the plans and mission manifests to ensure that manning is available, and the Panel supports that. She also reiterated the continued importance of persistent human presence in LEO to reduce risk for deeper space exploration in the future. The learning gained from that persistent presence is critical for gaining an understanding of the risks that may be faced in the future.

Dr. Sanders noted that Artemis and the prospect of landing astronauts on the Moon and exploring the lunar environment as a precursor to activities in deep space, is a hugely complex and inspiring endeavor. Mr. Paul Hill was introduced to lead the discussion of this challenging body of work.

Exploration Systems Development

The Panel reviewed ESD Program progress with the Acting Deputy Associate Administrator, Tom Whitmeyer. Although COVID-19 and four hurricanes have complicated ESD Program work, mission processing has continued, with some greater schedule risk to Artemis-2. As much of the world struggled with virtual presence and remote work, NASA was well served by their strengths in distributed team communications and data sharing with a large array of remote locations, including real-time development test data. Artemis-1, 2, and 3, Mr. Hill stated, all have real flight hardware and software in work.

Final Orion assembly is almost complete for Artemis-1, and the Space Launch System (SLS) Green Run hot fire is imminent, after which booster stacking will begin at Kennedy Space Center. Artemis-2 is also well into launch vehicle and spacecraft builds. Initial launch vehicle and spacecraft flight hardware production is in work for Artemis-3. The Exploration Upper Stage critical design review for Artemis-4 will be held in December, with a goal to enhance performance and safety.

For Artemis-1, Mr. Whitmeyer mentioned that NASA is now transitioning from development to launch processing and flight test operations. In his words, ESD is "passing the torch," which Mr. Hill reflected is a great milestone.

Mr. Hill stated that the Panel was privy to several other informative ESD briefings. Artemis Mission Manager, Mike Sarafin, provided a great description of the Artemis-1 and Artemis-2 mission milestones from launch through splashdown. Chief Safety and Mission Assurance Officer, George Deckert, presented updates on ESD software safety. ESD Safety and Mission Assurance Director, Thomas Hartline, discussed COVID-19 effects on supplier government mandatory inspection points. Finally, the Director of Cross-Program Systems Integration, Wayne Jermstad, elaborated on the ESD software assessment process.

During the week's insight meeting with ESD, Mr. Jermstad summarized the effort made by a broad agency and industry team to review Boeing OFT anomalies, and he assured the Panel that the lessons are being applied to ESD programs. Although the detailed lessons learned are proprietary, the Panel can reveal that ESD has added more integrated software tests for SLS and is evaluating more Orion test cases. Mr. Hill mentioned that there is, however, no integrated avionics and software test capability for ESD missions, including Artemis-1, 2 and 3.

The Panel has an ongoing concern that with each continuing resolution comes directly related and significant budget challenges which, when combined with the direction to be on the Moon by 2024, will increase pressure to make engineering compromises in order to stay on schedule–to a fault. That pressure is only going to increase as launch dates and 2024 approach. To be clear, Mr. Hill emphasized, this is not a *NASA* weakness; it is the reality of the difficult and complex work for which they are charged, exacerbated by unpredictable resources, of which Agency leadership is keenly aware. This *is* a weakness in the current federal budgeting environment however, and one that creates real risk for NASA and ESD, stressed Mr. Hill.

He further stated that as ESD "passes the torch" to flight operations, real physical risks manifest themselves instead of cost and schedule risks—high-energy systems in high-risk environments with little margin for error. In this regard, the Panel has applauded the Agency in previous

reviews for adding the SLS Core Stage Green Run. However, in addition to the budget-related challenges from continuing resolutions, the Panel has great concern about the end-to-end, integrated test capability and plans, especially for flight system software.

Although the agency expressed confidence that *accountability* for successful system development was clear, it is not evident that their current plan and processes take advantage of their lessons learned. Specifically, and as presented by ESD, there is no end-to-end, integrated avionics and software integration capability. Instead, multiple and separate labs, emulators, and simulations are being used to test subsets of the software.

The Panel refers the Agency to the NASA Engineering and Safety Center (NESC) report from September 8, 2020 (NESC-RP-20-01519, Impact of Commercial Crew Program Boeing Starliner Orbital Flight Test (OFT)-1 Software System Issues on Multi-Purpose Crew Vehicle/Space Launch System/ Exploration Ground System Programs and Exploration Systems Directorate Office), the details of which are proprietary, but the findings, observations, and recommendations are aligned with ASAP's concern. Specifically:

- Hardware and software are developed and validated by each program in separate labs using numerous simulators/emulators, but they are required to operate in flight as a single integrated system.
- SE&I weaknesses within ESD included a complex distribution of responsibilities, and a lack of technical accountability for the integrated system.

Mr. Hill stated that the NESC report makes the excellent point that as much as possible, flight systems should be developed for success with the goal to "test like you fly," in the same way that NASA's operations teams "train the way you fly, fly the way you train." As Ms. Kathy Lueders, HEOMD Associate Administrator, previously told the Panel, from a certain perspective, "the Boeing OFT in-flight anomalies were a gift." The ASAP believes that gift was awareness and the opportunity to apply the OFT lessons learned across the CCP. It is also an opportunity to apply the awareness and OFT lessons learned deliberately across ESD programs.

According to Mr. Hill, there is understandable focus on the upcoming SLS Green Run and Artemis-1. Production of real hardware and software is increasing, and each step must be executed flawlessly in preparing for these critical events. NASA and ESD understand both of these realities and have clear accountability. However, the ASAP recommends that in addition to *accountability*, ESD ensures their management and test *processes and practices* are aligned to "test like you fly"—to quote the NESC again. One element of that is more flight-like, end-to-end, integrated test capability, especially for new hardware and software and major upgrades, both of which will dominate NASA's experience in the decades-long Moon and Mars campaign.

Dr. Sanders thanked Mr. Hill for his synopsis of the ESD Program's efforts. She then stated that the Panel recognizes that the recent adjustments to the HEOMD in NASA included an office focused on Systems Engineering and Integration. The Panel's engagement with that office, however, indicates that this part of the organization is mainly intent on architecture development and allocation of performance requirements—a necessary function, but not the same as true technical, production-level engineering integration. The Panel clearly has persistent interest in integration, which will only become more challenging with the added

complexity of future missions. Advanced Exploration Systems (AES), which will shortly be discussed by Dr. George Nield, will only add to the importance of SE&I. Dr. Sanders indicated that the Panel strongly advises that NASA give increased consideration of the technical and organizational aspects of this aspect. The Panel plans to dive deeper into this aspect in the near term in order to better understand how the integration challenge will be managed.

Advanced Exploration Systems

Mr. Mark Kirasich, AES Deputy Associate Administrator, engaged with the Panel. Mr. Kirasich's organization has responsibility for Artemis-3 (the initial lunar landing mission) as well as subsequent exploration missions once they have been defined by the ESD SE&I organization. Currently, Dr. Nield stated, AES oversees five different programs: HLS, Gateway, xEMU (the next generation EMU), Exploration Capabilities (technology development), and Surface Mobility Systems (rovers).

The HLS Program has gotten off to a really fast start, Dr. Nield indicated. He said the Panel is very impressed with their accomplishments to date, specifically: the announcement of base period contractor selections in April 2020, base period contract awards in May 2020, and contractor certification baseline reviews in August 2020. Upcoming milestones include the issue of an Option A solicitation in October 2020, contractor continuation reviews in December 2020, up to two Option A awards for lunar lander development, and a 2024 crewed demo mission in March 2021.

In addition to the accomplishments previously mentioned, Dr. Nield stated that a Gateway memorandum of understanding (MoU) between NASA and the ESA, the Canadian Space Agency (CSA), and the Japan Aerospace Exploration Agency (JAXA) is in a U.S. government-wide approval process. The first pieces of flight hardware for the Habitation and Logistics Outpost (HALO) have been delivered.

Dr. Nield then discussed the status of the xEMU, which represents the first new spacesuit that NASA has developed in over 40 years. Right now, the build-up of the xEMU design verification test (DVT) suit assembly is on track for completion in December 2020. The first cooling garment prototype has been completed. The primary components to the Portable Life Support System (PLSS) backplate are in the process of being integrated. The Spacesuit Evaporation Rejection Flight Experiment (SERFE) is ready for launch to ISS on Northrop Grumman (NG)-14.

All of the development effort so far is being done by an in-house group at Johnson Space Center. Five suits are planned in the initial batch: one for DVT, one for qualification testing, one that will be sent to the ISS, and two that are scheduled to be used on the Artemis-3 mission. Dr. Nield indicated that so far, it looks like things are basically on schedule; however, the Panel has previously expressed their opinion that having a separate EMU Program Office may be appropriate to provide the necessary structure, visibility, and priority for such an important effort. The Panel will be watching the current group's progress going forward.

As for exploration capabilities, Dr. Nield detailed, three instruments were launched on Mars 2020 [Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE); the Mars Entry, Descent, and Landing Instrumentation (MEDLI-2); and the Mars Environmental Dynamics Analyzer (MEDA)]. The Water Processor Assembly Catalytic Reactor is in final assembly and testing, and

the hardware is planned to fly on SpaceX-21. The Brine Processor Assembly (BPA) is ready for flight on NG-15. The E4D exploration exercise device preliminary design review is complete.

AES is utilizing the mission analysis organization and processes established by ESD for Artemis-1 and 2. Specifically, the Exploration Mission Analysis Cycles (EMACs) synchronize integrated analysis across all missions and vehicles. The focus is on performance trades to ensure viable design for both nominal and contingency scenarios. The first Artemis-3 EMAC is underway and will be out-briefed in November 2020. Dr. Nield noted that the Panel believes that SE&I involves more than doing architecture studies and mission plans. So organizationally, it will be important to ensure that there are no "gaps" in the seams between programs, and during handoffs between offices.

Dr. Nield made one final general comment on budget. AES will clearly be significantly impacted by whatever decisions Congress decides to make on funding. The requested amount for FY21 was $4.6 billion; however, the continuing resolution level is only $1.5 billion.

Dr. Sanders thanked Dr. Nield for his perspective on the AES Program. She added that clearly, there are some emerging business models as NASA moves forward, and there will be interesting learning opportunities and resulting innovation to be seen; however, they are off to a good start.

NASA Aviation Safety and Sustainability

Dr. Sanders mentioned that since the Panel's last quarterly meeting, an assessment was undertaken by ASAP—at the request of the Administrator—to inform future decisions on the safety aspects of operation and sustainability of NASA's aircraft fleet. A team composed of Dr. Don McErlean, Mr. David West, Dr. Richard Williams, and led by Rear Admiral Chris Murray, did the majority of the fact finding, but the final product was coordinated with the entire Panel. The assessment was conducted from May 14 to July 14, 2020, and included interviews with a comprehensive group of stakeholders in the NASA aviation community in order to inform Panel assessments. Admiral Chris Murray addressed the results of that endeavor and the Panel's advice to the NASA Administrator.

The Panel found that aviation safety is well managed at NASA, stated Admiral Murray. There are very positive trends in mishap rates, injuries, and reporting. NASA's Safety Management System and associated procedures are well delineated in NPR 7900, Aircraft Operations Management. The Admiral indicated that the Intercenter Aircraft Operations Panel (IAOP), which is led by the Aircraft Management Division (AMD), is well received, and it performs the following functions: conducts audits of operational aviation units on a three year basis; conducts audits and builds remediation plans in response to any incidents that occur; and facilitates a forum for the aviation community to share lessons learned and best practices.

Admiral Murray spoke to the following observations made by the Panel. NASA is staffed, trained, and equipped to operate their own aircraft. Commercial Air Services (CAS) have been used to some extent, but the NASA centers are not optimally staffed to support such efforts. Increasing CAS efforts in the future needs to be balanced by the risk incurred with not being staffed accordingly.

Aviation safety training exists at NASA, but the completion of that training is not a requirement for personnel who work in aviation entities. The reporting of significant events up the organizational chain of command to headquarters leadership has been problematic, said Admiral Murray. For instance, there have been inconsistencies and delays in some cases, when middle management attempts to thoroughly investigate incidents to determine their root cause, rather than informing senior NASA leadership immediately that an incident has occurred.

NASA has a wide range of reactive metrics that AMD uses to characterize aviation safety performance, but proactive and predictive metrics need to be explored that are directly suited to preventing aviation incidents, stated the Admiral. The NASA Safety Center (NSC) could have a greater role in creating safety training for the aviation community, along with helping AMD develop more proactive and predictive aviation safety metrics.

AMD, the headquarters entity responsible for aviation safety, is located under the Mission Support Directorate, and is not represented as it should be in the NASA organizational structure, stated Admiral Murray. Due to this situation, funding for aviation safety, along with funding for aviation, is not considered to be "core" work, and has to be fought for on a yearly basis. AMD does not have a direct line of communication to the Administrator or Associate Administrator, a situation frequently encountered, but which represents an opportunity for improvement to better manage high safety risks.

Aging aircraft is a concern on every flight line at NASA, indicated Admiral Murray. The Center Directors or Science Mission Directors have been charged with leading efforts to update their aircraft when required. A process currently exists for fortifying and validating aircraft requirements, the Aircraft Advisory Panel (AAP), but it deals mainly with decision-making related to acquiring and retiring aircraft within a short-term timeframe. That Panel does not look across the entire NASA portfolio with priorities based on the long-term vision of the organization. A validated requirements process does not exist, stated the Admiral, where a centralized entity validates aviation requirements with the Administrator's strategic vision, and to meet the needs of the aviation stakeholders.

Upon completion of their insight engagements with NASA aviation leadership, the Panel provided the following advice to the Administrator. It was advised that the AMD be moved to the Safety and Mission Assurance Office. This move would allow the AMD to have a direct line of communication to either the Associate Administrator or Administrator. Admiral Murray expressed that this change would align the entity responsible for aviation safety under the technical authority for safety at NASA.

Additionally, the Admiral related that aviation operations and safety need to be considered as "core" work, and funded accordingly. A formalized process to report significant events to the Administrator needs to be adopted. A group, chaired by a member of headquarters leadership, needs to be created that balances the organization's aircraft requirements against the Administrator's strategic plan. This group would also have the responsibility for approving all aircraft recapitalization plans. The AMD, NSC, and key aviation stakeholders should collaborate on a yearly basis to review and expand the current reactive aviation safety metrics to include proactive and predictive ones. If NASA decides to expand the current level of CAS operations, a manpower study needs to be conducted to determine the correct manpower levels that are

required to adequately support the initiative. Aviation safety training should be required for all personnel who work in aviation entities. Finally, best practices should be compiled and shared among NASA centers and Science Mission Directorates.

Space Traffic Management

Dr. Sanders thanked Admiral Murray for presenting the Panel's assessment results of NASA aviation safety. To culminate the day's discussions, Dr. Sanders returned to a topic that the Panel discussed at the last quarterly, and which remains a top safety concern: micro-meteoroids and orbital debris and space traffic management (STM). Lt Gen Susan Helms was then invited to summarize the Panel's assessment of the status of this topic.

For several years, the Panel has expressed concern with the risk of damage to orbiting spacecraft and transiting astronauts due to orbital debris. The hazard from orbital debris has been recognized as a major issue in every program, and it is the dominant contributor to the calculations of loss-of-crew predictions for both commercial crew vehicles and Orion. It has also been a factor in two of the top safety risks for the ISS, stated Lt Gen Helms. NASA declared it an Enterprise Risk in 2017. The ISS has been maneuvered over two dozen times since its inception in order to avoid collision with orbital debris, but those maneuvers now seem to be required at an increasing frequency; within the last few weeks, Lt Gen Helms said, the ISS was maneuvered for the third time since the start of this year.

As was discussed in the ASAP's last quarterly meeting, space has become more congested, and the problem of orbital debris in space is growing at a concerning pace. For example, CubeSats and other small satellites are being launched with increasing frequency, and several companies are now deploying mega-constellations with hundreds, or even thousands, of satellites. Some of these satellites incorporate the use of electric propulsion and autonomous on-board maneuvers with very short turnaround times, increasing the difficulty of tracking and planning for collision avoidance with orbital debris. In addition, there have been many notable debris-generating events, added Lt Gen Helms, such as the intentional Chinese anti-satellite test of 2007, an event that raised the total orbital debris count by over 20 percent, and the unintentional collision between two space objects in 2009, one of which was a fully operational satellite belonging to Iridium, and the other a defunct rocket body of an old Russian launch from 1993.

The most recent ISS maneuver in September 2020 was necessary to avoid debris that had come from the breakup of a Japanese rocket body in 2019, adding dozens of pieces to the current count of over 23,000 trackable objects. And as the Panel mentioned in the last quarterly meeting, on a global level across the full international inventory, there are now several close calls on a weekly basis between numerous space objects, many of which are not capable of being maneuvered out of harm's way. Lt Gen Helms noted that the risk to the space environment, and to all who use it, must now be actively managed on a continuous basis, with robust tracking sensors, timely data, high-precision predictive algorithms, and similar to air traffic control, a tight network between those who track and those who are tracked, to ensure appropriate warnings are disseminated, acknowledged, and if possible, acted upon to avert catastrophe.

In the ASAP's last quarterly meeting, it was pointed out that, while NASA has a rightful concern about the serious hazards of orbital debris to the ISS and to other NASA spacecraft, the issue is

definitely a national and international problem, well beyond NASA's direct control. Orbital debris affects *all* entities that conduct operations in space, and it endangers those functions on which the public has come to rely—communications, navigation, and weather prediction, to mention just a few, said Lt Gen Helms. While the ASAP is principally focused on the serious hazards to NASA spacecraft and astronauts, the Panel recognizes that the issue must be tackled on a broader front. In the Panel's 2017 Annual Report, it was stated that "the U.S. government should seriously consider implementing significant improvements for Space Situational Awareness analyses and the provision of Space Traffic Management services, as well as expand its efforts in developing international strategies to reduce orbital debris generation in the future." The Panel further stated that it was important for "the U.S. to take a leadership role and for the National Space Council to address" the risk, and that the Panel believed "a lead Agency in the U.S. should be assigned to spearhead and coordinate efforts to prevent the generation of new debris and reduce hazards posed by existing debris."

The Panel was encouraged in 2018 when the National Space Council issued Space Policy Directive-3 (SPD-3), the national STM policy, which acknowledged and addressed the need to improve space situational awareness and manage the risks of orbital debris. SPD-3 promoted the implementation of a number of steps to address these risks and recommended that the Department of Commerce take responsibility for implementing a Civil STM framework. However, the Panel continues to be concerned that Congress and the Administration have not yet reached an agreement on the appropriate response to those recommendations, resulting in the U.S. government, industry and research partners, and international stakeholders not being able to move forward in a fully coherent manner to materially reduce the orbital debris risks and to increase the sustainability of space as a global strategic domain.

Lt Gen Helms indicated that it is well overdue that the U.S. exert some effective international leadership in the safety of space operations, and begin doing so by *designating* a Lead Agency to see to the provision of timely and actionable safety data to all space operators. She stated that the designated agency should work proactively within government, with industry, and in partnership with the international community in developing standards, guidelines, best practices, and "rules of the road" for safe space operations. Furthermore, this entity should support the conduct of scientific research and technology development for related areas, such as improved sensors, software, constellation management techniques, and methods for active debris management. Therefore, at ASAP's last meeting, the Panel made several formal recommendations, which Lt Gen Helms reiterated.

<u>The Panel recommends that the Congress:</u>

- Designate a Lead Federal Agency for Civil Space Traffic Management.
- Provide that agency with authority, immunity from lawsuits, and resources to do the job.
- In addressing the Space Traffic Management issue, require whole-of-government engagement, public-private partnerships, and collaboration between government, industry, academia, and the international community.

Additionally, the Panel recommends that NASA:

- Support and partner with the Lead Federal Agency once one is selected.

In the interim period:

- Because of the direct relationship to astronaut and spacecraft safety, ensure that risks having to do with micro-meteoroids and orbital debris, Space Situational Awareness, and Space Traffic Management are addressed in NASA's ongoing activities and in future budget requests.
- In collaboration with other government agencies and industry, develop and publish guidelines for Space Traffic Management focused on current and emerging challenges to maintain the safety of astronauts and spacecraft.
- Develop a proposal for a Space Traffic Management technology roadmap.

One development since the Panel's last quarterly meeting is that the National Academy of Public Administration released their long-awaited study on this subject, and recommended that the Department of Commerce take on the leadership role for STM on behalf of the United States. However, Lt Gen Helms reiterated that it would be Congress's responsibility to assign authorities and resources to the Department of Commerce before anyone could expect a comprehensive transition of leadership from the Department of Defense, the current manager of the space object catalog.

In addition, within the last month, several members of the Panel met with congressional staffers from the House Committee on Science, Space, and Technology to have a conversation about the overall problem of space debris, and to provide additional context behind the Panel's recommendations. Lt Gen Helms stated that the rich discussion that ensued was deemed helpful to further advance the awareness of not only the nature of this international problem, but also of the solutions necessary to arrest and manage the risks.

In summary, the Panel continues to contend that the issue of orbital debris not only presents a standing safety concern for NASA, especially for human-tended spacecraft, but it is also a growing threat to the sustainability of space as a peaceful domain for science, exploration, innovation, and commerce. It is the Panel's hope that comprehensive actions are soon taken by Congress, and supported by NASA, to advance risk reduction in a strategic and coherent manner.

Dr. Sanders thanked Lt Gen Helms for her overview of this growing issue, and stated that she cannot emphasize the importance of this issue enough. Dr. Sanders emphasized that progress is needed NOW.

In closing, Dr. Sanders reiterated something that the Panel has noted many times over the years—the importance of constancy of purpose. The Agency is on a positive and compelling vector toward space exploration. This is important to the nation and to all humanity going forward. In order to pursue this critical mission both effectively and safely, it is key that there be persistent focus on the way forward. Certainly, improvements and upgrades can be introduced as we get smarter, but the nation needs to keep our resources, including personnel, moving in a

positive direction. Not maintaining a steady, constant way forward is detrimental to progress, and definitely detrimental to a safety culture in doing so.

Before adjourning, Dr. Sanders acknowledged the significant and long-standing contributions of Dr. Don McErlean to the Panel and to NASA. Dr. McErlean has drawn on considerable personal experience and knowledge to make meaningful advice to further the safety of NASA's mission. After over 14 years of service, this is Dr. McErlean's final quarterly meeting with ASAP, although he will continue to participate in the Panel's efforts for the rest of this year. He has truly been value added, and speaking on behalf of the entire Panel, Dr. Sanders applauded his many, many efforts.

Dr. Sanders opened the meeting up for public comments. Randy Cruz of NASA commented that he always looks forward to ASAP's reports. He also expressed his appreciation of Dr. McElean's long-time contribution to the ASAP.

Ms. Hamilton adjourned the meeting at 1:00 p.m. EDT.

ATTACHMENT 1

Note: The names and affiliations are as given by the attendees, and/or as recorded by the telecon operator.

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