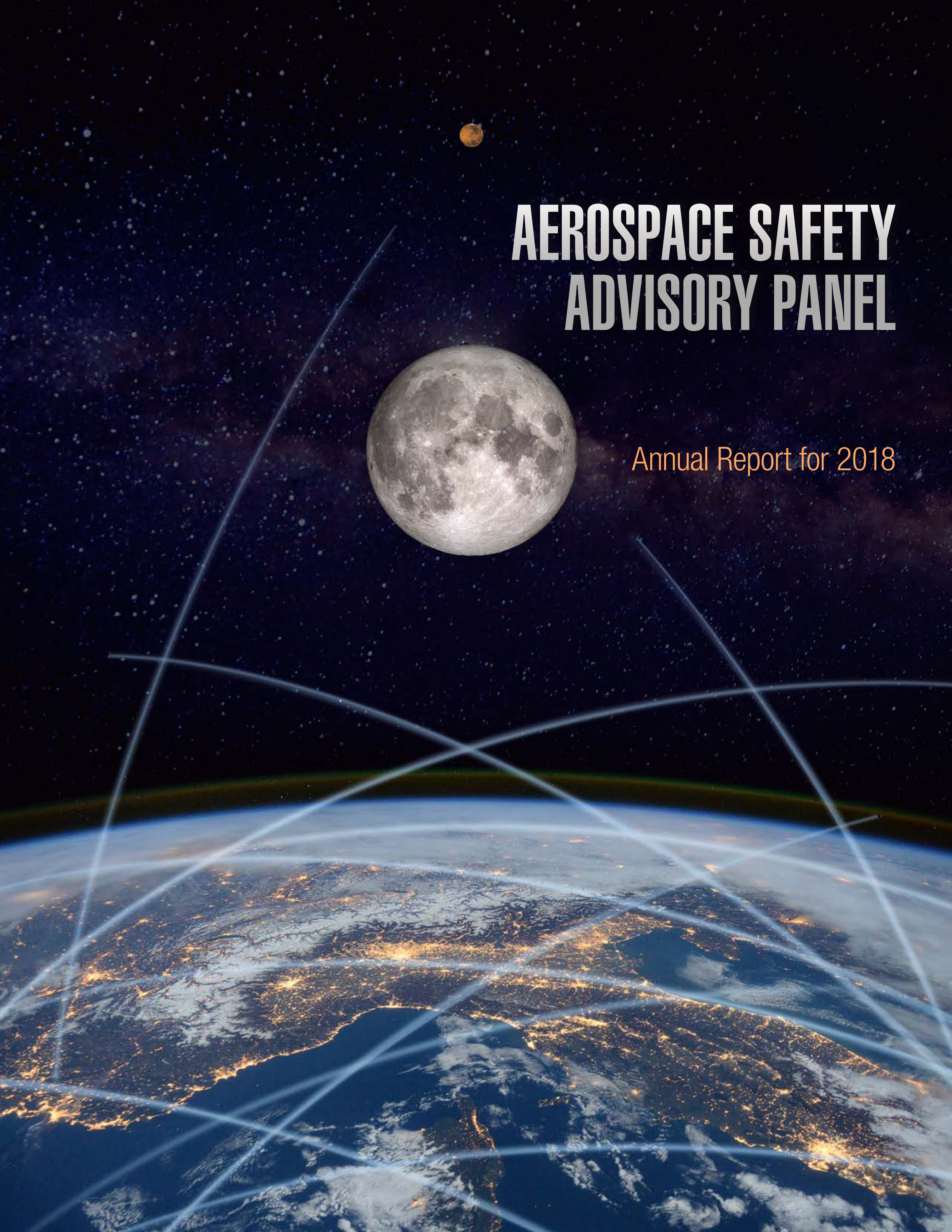
AEROSPACE SAFETY ADVISORY PANEL

Annual Report for 2018



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

January 1, 2019

The Honorable Jim Bridenstine
Administrator
National Aeronautics and Space Administration
Washington, DC 20546

Dear Mr. Bridenstine:

Pursuant to Section 106(b) of the National Aeronautics and Space Administration Authorization Act 2005 (P.L. 109-155), the Aerospace Safety Advisory Panel (ASAP) is pleased to submit the ASAP Annual Report for 2018 to the U.S. Congress and to the Administrator of the National Aeronautics and Space Administration (NASA). The Report is based on the Panel's 2018 fact-finding and quarterly public meetings; insight visits and meetings; direct observations of NASA operations and decision-making; discussions with NASA management, employees, and contractors; and the Panel members' past experiences.

NASA's role in leading the advancement of space technology involves pushing the envelope on technology development and human exploration. In seeking the benefits of these endeavors, there are immense uncertainties and inherent risks. Large-scale, technically complex space systems and operations in the hazardous space environment should not be overly constrained by schedule and cost but focus on achieving mission success and managing risk. We encourage NASA to continue to acknowledge these challenges as they balance the risk-benefit equation.

As both the Commercial Crew Program and Exploration Systems Development move beyond design into hardware production and test, we continue to note that NASA maintains focus on the requisite details for risk management and mission success without apparent neglect or omission of planned content. To date, but with technical challenges remaining, there has been no direct evidence that schedule pressure is driving decisions that will adversely impact safety.

As NASA transitions from development to operational launch and flight of its astronauts—something it has not done for several years, since the end of the Shuttle era—it is essential to remain cognizant of the perils inherent to space flight. Given the great uncertainties of the space operational environment, it is critical to maintain vigilance and attention to test results, engineering understanding, disciplined processes, and consideration of mitigation alternatives. We have often commented on the need for constancy of purpose for exploration, but along with that must go constancy of standards for certification, flight test, and acceptable risk.

Our advice includes a recommendation that NASA and the Congress agree on a mitigation plan to ensure continuing U.S. presence on the International Space Station until commercial crew providers are available. We also advise that NASA maintain a persistent presence in low-Earth orbit for the long term in order to mitigate the considerable risk of human exploration in the far reaches of space. We continue to urge serious attention to the hazards posed by Micrometeoroids and Orbital Debris, and we continue to recommend that the language in the NASA Authorization Act of 2005 requiring the establishment of a Presidential Commission for Human Space Flight Independent Investigations be reviewed and revised.

I submit the ASAP Annual Report for 2018 with respect and appreciation.

Sincerely,

Patricia Sanders

Dr. Patricia Sanders
Chair, Aerospace Safety Advisory Panel

Enclosure

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

January 1, 2019

The Honorable Michael R. Pence
President of the Senate
Washington, DC 20510

Dear Mr. President:

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NASA AEROSPACE SAFETY ADVISORY PANEL

National Aeronautics and Space Administration
Washington, DC 20546
Dr. Patricia Sanders, Chair

January 1, 2019

The Honorable Paul D. Ryan
Speaker of the House of Representatives
Washington, DC 20510

Dear Mr. Speaker:

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Chair, Aerospace Safety Advisory Panel

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The ASAP Charter and Quarterly Meeting Minutes can be found on: *https://oiir.hq.nasa.gov/asap/*

Preface

The Aerospace Safety Advisory Panel (ASAP) was established by Congress in 1968 to provide advice and make recommendations to the NASA Administrator on safety matters. The Panel holds quarterly fact-finding and public meetings and makes "insight" visits to NASA Field Centers or other related sites. It reviews safety studies and operations plans and advises the NASA Administrator and Congress on hazards related to proposed or existing facilities and operations, safety standards and reporting, safety and mission assurance aspects regarding ongoing or proposed programs, and NASA management and culture issues related to safety. Although the Panel may perform other duties and tasks as requested by either the NASA Administrator or Congress, the ASAP members normally do not engage in specialized studies or detailed technical analyses.

This report highlights the issues and concerns that were identified or raised by the Panel during its activities over the past year. The Panel's open recommendations are summarized in Appendix A. The full text of the recommendations submitted to the Administrator during 2018 is included as Appendix B, along with the closure rationale for recommendations closed in 2018. The Panel's issues, concerns, and recommendations are based upon the ASAP fact-finding and quarterly public meetings; insight visits and meetings; direct observations of NASA operations and decision-making; discussions with NASA management, employees, and contractors; and the Panel members' expertise.

I. Introduction and General Observations

A. Overview of Aerospace Safety Advisory Panel 2018 Activities and Program of Work

During 2018, the Aerospace Safety Advisory Panel (ASAP or Panel) conducted quarterly meetings hosted by Marshall Space Flight Center (MSFC), Kennedy Space Center (KSC), NASA Headquarters, and Johnson Space Center (JSC). In addition, ASAP members made insight visits to Ames Research Center, Armstrong Flight Research Center (AFRC), Langley Research Center, and Goddard Space Flight Center. We held in-depth dialogues with NASA Engineering and Safety Center (NESC) personnel. Two members participated in the Inter-center Aircraft Operations Panel (IAOP). The ASAP and the NASA Advisory Council continue to include representative participation in each other's meetings in order to facilitate broader perception and understanding of issues across NASA.

Much of the Panel's work this year has been focused on the qualification testing, analysis, and validation efforts of both the Commercial Crew Program (CCP) and Exploration Systems Development (ESD)—including human flight certification for CCP—as those programs approach decisions to launch their first uncrewed flight tests and prepare for the subsequent crewed flights. The assessments we draw from this year's activities will be detailed in subsequent sections of this report, but we have some general overall observations.

This year, the Panel made two new recommendations pertaining to the CCP. One will be discussed in the section of the report that contains our assessment of that Program, and one will be mentioned in a subsequent paragraph in this introduction.

The ASAP closed two formal recommendations this year. We closed our longstanding recommendation with respect to Radiation Risk for Deep Space Missions. Although we are still concerned about radiation, we believe that NASA is addressing the risk in a manner that allows them to maximize their risk mitigation options. We will continue to monitor progress in this area. We also closed our recommendation addressing Processes for Managing Risk with Clear Accountability. NASA issued NASA Procedural Requirements (NPR) 8000.4B, which established a policy to meet our concerns on managing risk. We will, however, be looking for evidence that this policy is effectively implemented as NASA makes risk acceptance decisions in the future. We will pay particular attention to the scope and scale of risk acceptance decisions, in that those decisions acknowledge the consequences of accepting—and not accepting—the risk.

Several recommendations remain open. The Panel will discuss its recommendation on the Practice of Systems Engineering and Integration Principles by CCP Providers later in this report. We have seen good progress towards resolution of recommendations on Security Clearance Policy and International Space Station (ISS) De-Orbit Planning, and we remain engaged with the Safety Audit processes. All of these will be covered in subsequent sections. The issue we described in our recommendation on Human Space Flight Mishap Response Procedures remains a concern. We continue to recommend that the language in the NASA Authorization Act of 2005, which requires establishment of a Presidential Commission for Human Space Flight Independent Investigations, be reviewed and revised to address the concerns previously articulated in our Annual Reports and elsewhere. Action now is essential as we near the re-establishment of our human launch capability.

B. Transition from Development to Operations

Both CCP and ESD continue to move well beyond design and into hardware production and test with first flights approaching. The Panel continues to note that both programs maintain focus on the requisite details for risk management and mission success without apparent neglect or omission of planned content. To date, we still see no direct evidence across NASA that schedule pressure is driving decisions that will adversely impact safety, but important testing remains. As with all testing of complex space hardware, inevitable discoveries will likely necessitate the careful weighing of all the technical and operational aspects of risk-benefit trades.

CCP continued to make progress in 2018, even as the demo flights for both providers slipped from 2018 into early- to mid-2019, with corresponding delays to the crewed flights. Both providers are working methodically through the remaining technical issues and continue to work with NASA on gathering and submitting the information required for certification. Even as we remain aware of the importance of having a U.S. launch capability, and the recent Soyuz abort reminds us of the criticality of having more than one means of transport to low-Earth orbit (LEO), the ASAP has seen no direct evidence from the CCP that schedule pressure is resulting in decisions to remove critical content related to risk mitigation. The Panel will continue to closely monitor the situation. NASA should continue a constant, clear articulation of those elements that must be demonstrated on both demo flights and that are required to mitigate risk for crewed flight. We have often commented on the need for constancy of purpose for exploration, but along with that goes constancy of standards for certification, flight test, and acceptable risk.

The schedule slip into 2019—along with the remaining risk of further schedule fluidity due to the remaining technical issues and potential lessons learned during the demo tests—potentially puts NASA at risk of not being able to maintain a U.S. presence on the

Event	Scheduled (as of Dec. 2018)
SpaceX Demo 1 (No Crew)	Jan 2019
Boeing Orbital Flight Test (No Crew)	March 2019
SpaceX Demo 2 (Crew)	June 2019
Soyuz 59 Launch	July 2019
Boeing Crewed Test Flight (Crew)	August 2019
PCM 1 (SpaceX/Boeing)*	October 2019
Soyuz 58 Land	October 2019
Soyuz 61 Launch	October 2019
Soyuz 59 Land	February 2020
PCM 2 (Boeing/SpaceX)*	February 2020

*PCM flights subject to change based on the performance of the test flights

FIGURE 1. CCP Events and U.S. Access to the ISS

ISS, given the current constraints under which the Agency is operating. It would be appropriate for NASA and the Congress to agree on a mitigation plan to ensure continuing U.S. presence on the ISS until the commercial crew providers are available. (See Figure 1)

Consequently, the ASAP has made the following Recommendation (2018-04-02) for Action to Ensure U.S. Access to the ISS Given CCP Schedule Risk:

> Due to the potential for delays in the schedule for the first CCP flights with crew, senior NASA leadership should work with the Administration and the Congress to guarantee continuing access to ISS for U.S. crew members until such time that U.S. capability to deliver crew to ISS is established.

Nearing the launch and flight of NASA astronauts, it is critical to remain cognizant of the perils inherent to space flight. NASA is transitioning from development to operations in this regime—something it has not done for several years, since the end of the Shuttle era (see Figure 2). Space can be a decidedly hostile environment, and while there is no excuse for negligence in the safety arena, it is impossible to control, eliminate, or mitigate every risk. "Safe"—as a term used in relation to space exploration—does not have the same connotation as the word in typical, day-to-day life. Calculations and numbers are often used to attempt to quantify the degree of risk and are useful to identify hazard drivers and guide design approaches, but not to definitively identify the degree of exposure involved. Given the greater uncertainties of the space operational environment, the focus should be on test results, engineering understanding, disciplined processes, and consideration of mitigation alternatives—e.g., redundancy and high reliability—rather than any specific metric.

The transition from development to operations will be a challenge and will require CCP's and ESD's constant and concentrated focus.

FIGURE 2. Time Gap Between Space Shuttle and CCP Launches

C. National Space Policy Directives

With the re-establishment of the National Space Council and the issuance of three Space Policy Directives, the Panel has a few comments.

Space Policy Directive One prescribes "an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations." This clarity in direction is welcomed, but we have two observations.

1. In order to mitigate the considerable risk of human exploration in the far reaches of space, it is imperative that NASA maintains a persistent presence in LEO where it can test the technologies necessary for interplanetary voyages with its requisite life support and to continue its understanding of the impacts of space travel on human physiology.
2. As NASA enters into new arrangements with commercial and international partners, we strongly suggest that an examination of the CCP business model—as well as the lessons learned from the ISS—be taken into consideration. There will be tremendous value in understanding the complexities that are experienced in managing and mitigating risks that may be shared by multiple national and industrial partners.

Space Policy Directive Two stresses that "it is important that regulations adopted and enforced by the executive branch promote economic growth; minimize uncertainty for taxpayers, investors, and private industry; protect national security, **public-safety** [emphasis added], and foreign policy interests; and encourage American leadership in space commerce." The Panel is reassured that public safety is included in the consideration of space-related regulations but encourages the consideration of other safety aspects as well.

In last year's report, the ASAP noted that damage from Micrometeoroids and Orbital Debris (MMOD) was a dominant—if not the highest—safety risk for the CCP, ESD, and the ISS. We urged the U.S. to take the lead in a response—with the National Space Council addressing the issue—and assign a lead agency to spearhead and coordinate efforts to prevent new debris generation and reduce the hazards posed by existing debris. We were, therefore, encouraged that Space Policy Directive Three focused on this risk. Of course, it will be essential that meaningful actions are taken in response to the Directive to address a significant safety hazard.

D. Future Work

In the coming year, the ASAP plans to continue focused effort on the CCP certification efforts and on ESD's preparations for the Exploration Mission (EM)-1 and EM-2 test flights. We will also examine testing and technology development progress toward mitigating the risks of lunar and Mars exploration. NASA has initiated a review of the safety environment and culture of the two CCP providers, and the ASAP will be monitoring that activity. In addition, the Panel will direct its attention toward a deeper understanding of the safety culture at NASA, the Enterprise Protection Program (EPP), and various aspects of aircraft operations. We have outlined our program of work and insight discussions accordingly.

II. Commercial Crew Program

Over the past year, NASA provided the Panel several updates and status briefings on the successes and ongoing challenges in the CCP. Both providers continue to progress, meeting critical milestones and documentation deliverables. In addition, while Boeing and SpaceX have remaining challenges to overcome, they both are closing in on the first uncrewed flights of their hardware. As the Program begins the important phase of flight testing and certification of the systems, the Panel remains closely focused on the overall safety and risk posture leading up to the crewed missions. We have identified several areas of interest.

FIGURE 3. SpaceX Dragon at Test Facility

A. Certification

The CCP is continuing progress on understanding and implementing a certification process for the commercial crew vehicles. It is important to note two aspects of the certification process:

1. The certification process that NASA is undertaking is limited to accepting the vehicles for use by NASA astronauts on a specific mission profile rather than a general safety certification process typically used by the Federal Aviation Administration (FAA) for aircraft.

2. Unlike previous human-capable spacecraft developed for NASA missions (ISS, Shuttle, Apollo, etc.), NASA does not own or control the commercial crew vehicle designs.

The certification process that NASA and the commercial providers have agreed upon encompasses a comprehensive system of documentation, data deliverables, and reviews—all of which are necessary for NASA to understand the system design and operational margins as well as the appropriate operational envelope. While NASA has some experience with qualifying vehicles in this manner, having used a similar process with Evolved Expendable Launch Vehicles for high value payloads as well as its experience with the Commercial Cargo Program, the CCP will for the first time be certifying commercially developed vehicles for human space flight. The Panel again wants to emphasize the importance of a strong, robust certification process that will ensure that data submitted to validate the design meets the stated requirement with the expected margins and that the hardware delivered reflects that design. The data submitted—negotiated between the provider and NASA—can be measurements, test data, or analysis. Sometimes it involves witnessed testing or physical inspection. The thorough data analysis or other information received must ensure that the delivered hardware is built to requirements and is well understood. NASA engineers are responsible for review of the data and the validation that the provider has demonstrated meeting the certification conditions. A clear set of guidelines for how to proceed when a certification condition is inadequate, and what defines "inadequate," needs to be specified and communicated to the workforce. In addition, it should be recognized by all parties, both internal and external to NASA, that the certification process is not merely a "paperwork" process; it involves considerable detailed technical activity by both NASA and the partners. It is the completion of NASA's technical certification of the design, combined with a mission-specific flight readiness review, that assures the crew will fly on an adequately risk-managed spacecraft. For both providers, the uncrewed demo flights serve as key test and validation milestones for demonstrating the performance of the integrated system and subsequent risk mitigation for the follow-on crewed flights. As NASA, SpaceX, and Boeing continue to manage a demanding schedule and important qualification tests, it is important that the Program clearly identify the elements of the

FIGURE 4. Boeing Starliner

systems and their configurations that must be tested and proven on the uncrewed demo flights before launching with crew on board. The ASAP made the following Recommendation (2018-04-01) on Required Actions for Crewed Flight Test Risk Reduction:

> NASA should confirm and then clearly communicate the required content and configuration for the upcoming CCP test flights (Demo-1 and Orbital Flight Test), specifically those items that must be successfully demonstrated prior to the first crewed flights.

B. Appropriate Use of the Loss-of-Crew Number

In last year's report, the Panel discussed the CCP Probabilistic Risk Assessment (PRA) requirement for Loss of Crew (LOC) and the fact that the most valuable element of the PRA analysis is the identification of the major risk drivers, which can then be mitigated by design changes, additional testing, or other controls. This year, we again reiterate that PRA values should not be viewed as an absolute measure of the actual risk during operations. The LOC numbers, while important, should not overshadow the focus by the providers and the Program to identify the high-risk areas and work to mitigate those risks by either design approach or operational procedures. It is important for NASA to evaluate the many other parameters available—including redundancy in designs, reliability, identified hazards and their controls, as well as the certification process—in addition to understanding the data behind the LOC calculations, in order to determine the resultant risk posture for the commercial vehicles. The discussion must include an acknowledgment that as the Program moves from design and qualification to operations, a constant monitoring of operating environments and procedures is mandatory to ensure that the risk posture remains well understood. Relying on only the LOC number to describe program risk moving forward is insufficient and misleading.

Using the LOC calculations as a tool currently identifies two of the primary risk drivers for both providers—MMOD damage during the docked phase and parachute performance—which remain the same as those identified last year. The MMOD analysis continues to evolve as the orbital debris models are updated. MMOD will continue to be an important safety issue for the near future for all space vehicles until proactive steps are taken to manage and control the problem. In the meantime, the providers and NASA have been working to refine the understanding of the current environment and create mitigation strategies to minimize risk exposure. Parachutes remain a challenging area for both providers. Both providers have experienced technical challenges, albeit different ones, related to the deployment and performance of their parachute systems. The Program has established a defined regime of parachute testing and qualification requirements, including six reliability tests for each provider. The ASAP firmly believes that before the crewed missions are conducted, each provider's parachute systems must be fully qualified, including successful completion of the reliability testing with a consistent design. Qualification tests, which are tests designed to prove that the final design meets requirements, should not be confused with design and flight testing, the purpose of which is to collect data to establish the final parachute configuration. We encourage the Program to continue to look carefully at the parachute qualification process for both providers.

Another significant risk driver for SpaceX, still under investigation, is the Composite Overwrap Pressure Vessel (COPV) design and use. Earlier LOC calculations indicated that the COPVs were of concern. As the investigations continue, the Panel will be interested in learning the relative risk this subsystem contributes to the overall system risk posture, as well as mitigations to that risk should it prove to emerge as a major factor.

C. SpaceX Composite Overwrap Pressure Vessel Redesign

Throughout the year, NASA briefed the ASAP on the progress of COPV testing and investigations into the COPV failure and subsequent redesign to the improved COPV 2.0 and its qualification testing. The Panel has consistently maintained that understanding COPV behavior in the densified cryogenic environment and identifying all the potential ignition scenarios are critical to controlling potential hazards. Testing to date has identified a potential ignition source related to fiber breakage, but the impact of this ignition source has yet to be determined. Consequently, while NASA and SpaceX have made significant progress in understanding the COPV 2.0 behavior in its environment, we believe that the team has yet to arrive at a clear definition of the risk posture or mitigation strategies related to operations with the redesigned COPV. The testing is continuing, and we will follow the results as they develop. It is imperative that the Program understands the potential hazards, the controls of those hazards, and the margins involved, and also ensures that the operating environment stays within those margins if the redesigned COPV tanks are to be implemented for crewed flights.

D. SpaceX "Load and Go" Procedure

Together with the COPV testing, the CCP has been investigating the merits and risk posture of proceeding with the SpaceX "load and go" operational approach for the Falcon 9. To achieve the desired performance of the launch vehicle, hardware design and ground procedures have been developed to operate with a specific density of fuel, requiring last-minute fuel loading. Consequently, the crew ingresses the Dragon just prior to the fuel being loaded, in contrast to earlier human space flight vehicles, where the crew ingressed an already fueled vehicle. Each crew-boarding scenario carries different hazards. The NESC has independently studied the load and go procedure and provided a thorough report that identifies the hazards and available controls. Based on the NESC report, the CCP has decided that the load and go concept is viable if subsequent analysis is adequate and if verifiable controls are identified and implemented for all the credible hazard causes that could potentially result in an emergency situation or worse.

The Panel agrees that if all the appropriate steps are taken to address the potential hazards, the risks of launching the crew using the load and go process could be acceptable. However, the Panel is primarily concerned about the COPV issue, which must be resolved regardless of whether the crew enters the Dragon before or after fueling the Falcon 9. The viability of the proposed load and go procedure must be evaluated considering the data, margins, and required operating environment to control hazards associated with the COPV 2.0 design and understanding any residual risk. Upon gaining a greater understanding of the margins related to operating with the redesigned COPV, NASA should re-assess the adequacy of the controls associated with the load and go procedure to ensure that the operating environment dictated by this process is within the acceptable safety limits of not only the COPV 2.0 tanks, but all other identified hazards as well.

E. The Use of Systems Engineering and Integration

In 2018, the Panel continued its investigations into the appropriate use of Systems Engineering and Integration (SE&I) principles as applied to the CCP. In the context of the Panel's investigations, using SE&I principles means having a process to understand the margins of the integrated system design, verifying those margins through test and analysis, and controlling both the configuration and the operation of the system to ensure those margins exist when flown. These principles are essential, in both culture and practice, to achieve the best possible outcomes for human space flight safety. Because Boeing is utilizing a traditional, well-established SE&I approach, the Panel has focused on understanding the SpaceX approach. From the beginning, SpaceX has adapted a spiral development model, and that model requires a different methodology for SE&I. Because of the rapid movement from design, to test, and then modification, we wanted to learn more about how the company was controlling design, manufacture, and operations in the context of their margins—essentially, if a traditional SE&I process was not being used, what equivalent process was being used instead.

Throughout 2018, the Panel was able to have a more in-depth discussion on SpaceX's internal tools that are used to track hardware development through design and production. SpaceX's current SE&I approach uses workflow process tools (software) that deliver verification review data via a "Bill of Design" and track changes to the hardware. The tools include traceability from component design drawings and their design notes through to production procedures and automate design change propagation through other appropriate products. In addition, the use of the tools automatically catches important deviations such as human error in data entry and anomalous qualification testing outcomes, whereby any design changes are immediately visible to all design engineers and associated disciplines. SpaceX has allowed NASA almost complete access to this system, and NASA engineers can gain virtually immediate information and insight into the current configuration. NASA is fully engaged with this tool and has instituted audits of the SpaceX process to ensure the tool is widely and comprehensively used.

SpaceX has also shared statistics on the tool's use. Growth has been phenomenal, going from about 10,000 user entries per quarter to about 50,000 to 60,000 user entries per quarter. It is very clear that members of the technical staff are accessing and using these systems. While the tool represents a state-of-the-art approach and differs somewhat from traditional systems engineering, there is no question that it provides much the same data and does so more quickly. The Panel is satisfied with what it has learned regarding the SE&I approaches by both companies and will continue to monitor the evolution of the safety culture at both providers.

III. Exploration Systems Development

A. Overview

The Panel reviewed the Orion, the Space Launch System (SLS), and the Exploration Ground Systems (EGS) Programs at each quarterly meeting. All three Programs are progressing, but technical and managerial issues continue to be challenges and could impact schedule. Although Orion, SLS, and EGS are three separate Programs, they comprise a "system of systems." When they are operated together as components of that system of systems, we have termed the overall operational entity the "ESD System" for convenience.

The nearest milestone critical to overall safety is the Ascent Abort-2 (AA-2) Test, scheduled for April 2019. This test will validate the crew module's ability to safely separate during a launch abort and then subsequently maneuver the crew out of danger. The ASAP strongly supports this test and the decision to gather the data as early as possible.

The ESD Program has made significant progress in many areas. First is the continued successful execution of the full-scale structural testing. Full scale testing, where the real components are subjected to actual loads, is longer and more expensive than analytic approaches but provides more accurate data. Since the ESD system is to be NASA's deep space transportation system for the future, this method provides the crucial data needed for both current and future structural assessments.

FIGURE 5. AA-2 Test Elements

Other progress includes Orion initial power-on testing and successful structural qualification. The Orion Program has also successfully completed all eight of the scheduled parachute qualification tests. Finally, the European Service Module (ESM) was received in the U.S, which represents an important milestone for the ESD System as it works towards the EM-1 flight test. However, technical challenges remain. Core stage manufacture and qualification tests and the ESM propulsion system continue to raise issues that affect both safety and schedule. In addition, flight control and ground system software has been a continuing concern and risk throughout the Program and remains an element on the critical path to EM-1 and later launches. While progress is being made, software validation remains a considerable technical risk until completed. Software validation and verification is required before declaring the software operational, and it is not uncommon during this process to discover issues that need correction.

The continuous risk management process governs the entire safety environment. Throughout the year, the ASAP conducted a very extensive discussion of this issue. These discussions covered the identification of the top risks, their mitigation, and the adjudication by leadership. A clear, integrated risk management process—in a system development that entails three separate programs (SLS, Orion, and EGS)—is crucial for tracking and maintaining control of the ESD System overall risk. We found that each of the key programs identifies, manages, and tracks risks in a similar fashion. The highest identified risks from each program are automatically elevated for review by NASA Headquarters. The Panel supports this chain of communication and the clear process to determine what risks are elevated and why. However, we do not yet know enough about how these elevated risks are integrated across all three programs in order to analyze their interdependencies. Risk integration—and the evaluation of those integrated risks—is a critical portion of risk management. While we did not find any areas that were obviously being untreated, we will continue work in the upcoming year to better understand how NASA is integrating and controlling risk at the ESD System level. In addition, the ASAP has observed that many of the risks automatically elevated to NASA Headquarters for review seem to be risks that are programmatically oriented (cost, schedule, funding) as opposed to technical risks that require engineering design or operationally targeted solutions for mitigation. While we have no doubt that the programmatic risks do indeed represent a risk to schedule progress, we feel that the technical risks can most directly affect safety.

B. Orion

Orion, the crewed vehicle being built to carry humans beyond LEO, continues to be a prime focus area for the ASAP. In addition, Orion has also emerged as a key element of the lunar Gateway. Gateway is being proposed to implement the directive issued by the Administration and National Space Council to establish operations in the Moon's vicinity and facilitate ground or surface operations. Gateway is conceived as a near- and short-term, crew-tended platform, which may be human rated only when the

FIGURE 6. Orion Heat Shield

Orion is docked. This plan further highlights the importance of establishing strong reliability, survivability, and safety systems on the Orion capsule.

During this year, the ASAP continued to review several areas of concern in the Orion Program. Overall, the ESD System was designed to methodically collect data and expand operational experience to build confidence in the integrated space system. Large-scale integrated system tests, including the flight tests, were designed to ensure that important data and knowledge required to properly mitigate safety risk would be obtained before sending humans beyond LEO. In carrying out this approach, Exploration Flight Test-1 returned data that resulted in a completely different approach to the design and manufacture of the capsule heat shield. This new system relies on blocks of heat resistant material, joined to a backing with the inter-block spaces filled with a gap-filling compound. The new system has a potential failure mode that involves the differential ablation rate between the block material and the gap filler which could lead to heat shield failure. Fully understanding this failure mode can only be achieved through full-scale flight test, because no ground facility can generate the extreme environmental conditions over a large enough area to fully validate the shield's integrity. The acquisition of critical heat shield thermal performance data is required to ensure crew safety, and only flight test can obtain this data. Despite this, ASAP has now learned that recent decisions about launch commit criteria could result in a situation where the EM-1 flight test could occur without the ability to obtain this data. This could be caused by the lack of a properly functioning avionics box that collects and stores the data from the heat shield instrumentation. Without this critical data collection, one of the main objectives of the flight test could be compromised. If the avionics box fails, the back-up plan for heat shield verification is to visually examine the EM-1 heat shield for damage and/or potentially deploy an airborne asset during the re-entry phase to attempt to acquire infrared imagery of the Orion capsule as it returns to Earth. This approach is driven by the desire to avoid a launch delay in order to roll back the system to the Vehicle Assembling Building for avionics box replacement. While we understand the reticence to accept such a delay, neither option guarantees enough information will be gathered to provide the needed understanding of heat shield performance. The ASAP position is that NASA should aggressively research alternate means to collect the data onboard if the avionics box fails. Redefining flight test scope and requirements as important as these must only be done after an exhaustive search for alternatives and with a thorough understanding of the change in risk posture for subsequent human flights.

C. European Service Module

In the past, the ASAP has voiced concerns with several aspects of the ESM propulsion system. The Orion Program has been systematically evaluating and addressing these areas of concern over the last year. The amount of work involved in analyzing the system at a very detailed level to understand the flow paths, physics, and system behavior is very impressive. In many cases, the program has—through engineering analysis—achieved a greater understanding of the system that allowed it to retire risk, increase hardware inspections to understand reliability, or make modifications to increase performance. The Panel applauds these actions and feels comfortable with many of the resolutions. However, we remain very concerned and have reservations about the ESM propulsion system's serial propellant system design, along with several of the zero-fault-tolerant design aspects of this system. We understand the rationale and constraints that drove the decision for a serial system in the initial stages of the Program. Several additional failures related to valve performance and integrated system behavior, in addition to the existence of the single-point failures, have only served to underscore the inadvisability of relying on a single-feed system for crewed missions to deep space for the longer term. Our understanding—documented by a Program Manager memorandum—had been that the Program would move to a parallel system after the first three flights. However, during our fourth quarterly meeting, we received information that the Program may be reconsidering this approach. At this point, it is not clear to the Panel that the Program has developed a thorough understanding of the risk posture, reliability, and crew survivability with the current serial approach. The remaining single-point failures represent significant residual risk to the crew. The Panel sees no compelling reason to alter the initial documented approach that implements a parallel system at EM-3 and beyond.

D. Launch Preparations for Exploration Mission (EM)-1 and EM-2

The Environmental Control and Life Support System (ECLSS) is a principal EM-2 element that needs completion and qualification. The ASAP continues to be concerned about whether this system will be fully tested, qualified, and ready to support the crew launch for EM-2. Although NASA has informed the Panel about ECLSS testing, which is currently scheduled in 2021, we have not seen the plan for validation of the entire integrated system. While some components of the system are being operated on the ISS for microgravity experience, this component work does not substitute for integrated system operational validation. We will continue to seek and request information on this plan in the upcoming year.

FIGURE 7. Ground System Mobile Launch Platform

Similar to the Panel's Recommendation (2018-04-01) on CCP, we feel that the Program should clearly identify which systems or components must absolutely be present on EM-1 for them to be considered qualified for operation on EM-2. Crew risk mitigation on EM-2 depends on the flight demonstration of some elements of various systems. It is our position that those components, parts, or systems need to be directly identified by the Program and those essential elements be incorporated before the EM-1 flight is launched.

IV. International Space Station

A. Overview

The Panel continues to be impressed with the ISS Program's ability to deal with the challenges of operating in the space environment in such a way as to make it seem "normal" business.

The ISS itself remains a highly unique international asset and is the one and only habitable venue currently available where all space-based exposure factors and conditions are encountered. The Panel commends NASA and its International Partners for the science that has been accomplished onboard, with thousands of research projects underway or completed by investigators from many countries. Specifically, there have been 2,582 investigations conducted since the beginning of the Program, with over 3,000 investigators involved and over 1,500 publications. The work being done on the Station is very much an international activity, with the participation of 103 countries to date in research or educational activities. These are extraordinary accomplishments, especially in the context of competing demands on crew time.

The ISS has also proven to be invaluable as a test bed for spacecraft systems and hardware and as a platform for scientific research. Of particular interest for future human exploration missions are the health and medical issues identified by the NASA Health and Medical Technical Authority (TA). Some of these are well-known, such as bone demineralization in microgravity, and some are emerging, such as Spaceflight Associated Neuro-Ocular Syndrome. These physiologic changes, and

FIGURE 8. ISS in Orbit

many others, are related to crew adaptation to the space environment, but they can prove pathologic both during missions and on return to a gravity environment. It is quite possible that additional unanticipated physiologic changes may become apparent—with a corresponding increase in health-related space flight risks—as more astronauts participate in longer duration flights. The ISS offers an opportunity to understand, through observation, how human health evolves in the space environment. As a national laboratory, it is the ideal platform to observe, document, understand, and develop mitigation strategies for these changes and risks. It is best and safest to conduct these observational and research activities in LEO to the extent feasible. The Panel regards the evolving evidence base on human health-related risks in space, along with NASA's research efforts to understand and mitigate these risks, as highly relevant to overall mission safety. We look forward to learning more about these issues as an item of interest over the next year.

The Station remains a very busy place. The crew recently completed a series of extravehicular activities (EVAs) targeted at replacing a failed latching end effector on the Canadarm. The arm is now in a healthy configuration for interaction with both commercial cargo vehicles and the forthcoming commercial crew vehicles, which are scheduled to arrive at the ISS later in 2019. CCP transition to the operational phase will be an important, long sought milestone for the ISS Program and should add flexibility to operational planning. Until that time, however, the Panel urges NASA to closely monitor CCP's ongoing evolution, consider possible scenarios, and lay plans to ensure that the appropriate skill sets are available onboard to adequately maintain and sustain the U.S. Orbital Segment. In particular, the Panel believes that it is prudent for NASA to consider contingency plans for continuity of operations on the ISS, given the schedule risk still inherent in the CCP. There are considerable safety issues involved should the Station be unmanned or undermanned, even if it is only temporary, or if it is only the U.S. segment that is affected. At the same time, we recognize that it is undesirable from a human space flight safety perspective to rush the certification of new launch vehicles for transport to the Station in the face of these ISS mission pressures.

Over the course of the last year, the ISS experienced a number of relatively minor hardware issues. One in particular caught the Panel's attention: a power fluctuation anomaly in one of the EXPRESS racks related to a payload that had updated its internal design. Despite the design change, an updated integrated power analysis of the overall rack had not been conducted. No notable safety issue ensued, and the payload was taken offline; however, this event does speak to the need to remain vigilant about hardware and software configuration control. NASA is reemphasizing that need to its payload customers.

The Panel is pleased to note that plans have been developed related to the maintenance and management of the extravehicular mobility units (EMUs) and other EVA hardware for the remaining ISS life. NASA is tracking and examining systems and components for retirement, replacement, or refurbishment. One of the major adjustments the technical community had to make with the retirement of the Space Shuttle was the need to conduct regular, planned maintenance on-orbit rather than in dedicated ground facilities. In addition, NASA is considering a number of major upgrades to the EMUs—spacesuits, helmets, heat exchangers, etc. The Program is examining how they can be demonstrated or incorporated into Station activities. It is using a similar approach for the ECLSS—both air and water—to improve and demonstrate significant run times on these new systems for the higher reliabilities needed for exploration missions. As NASA considers options to potentially extend the ISS lifetime, it will also be important for the Agency to continue to monitor the age, condition, and performance of other kinds of equipment on the ISS. The Panel will continue to track this area.

B. Recent Mishaps

Two recent events demonstrate that space flight is inherently risky: a pressure leak on the ISS, and an abort during a launch of the Russian Soyuz.

On August 29, 2018, as a result of a slight decrease in pressure being detected onboard the ISS, a small hole was discovered in the hull of the Soyuz 55 capsule. NASA formed an independent investigation team and assessed the Russian Federal Space Agency (Roscosmos) Commission's results to provide risk assessments to the ISS Program. The crew's repair appears to be very effective, and increased damage to the pressure shell in that area and/or crack propagation are not considered likely. To ensure there were no further issues with the repair, the crew performed daily monitoring of the leak site using the on-board

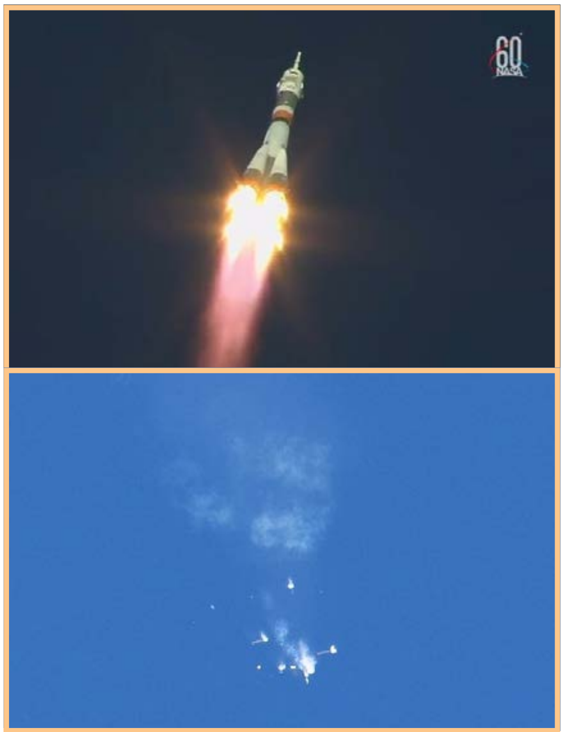

FIGURE 9. Soyuz MS-10 Launch and Abort

FIGURE 10. Astronaut Nick Hague Welcomed Back Safely

ultrasonic leak detector equipment. At this point, it appears that NASA and Roscosmos are fully in agreement on their analyses and risk assessments.

Although the root cause of the hole in the Soyuz has not yet been determined, neither Roscosmos or NASA believe it resulted from an MMOD impact. Nevertheless, MMOD continues to be considered the top safety risk for ISS astronauts, based on potential damage to the Station itself or to a Soyuz or commercial crew vehicle attached to ISS. In the Panel's 2017 Annual Report, we recommended that the National Space Council assign a lead agency in the U.S. to spearhead and coordinate efforts to prevent the generation of new debris and reduce the hazards posed by existing debris. Space Policy Directive Three, which was approved on June 18, 2018, assigned that responsibility to the Department of Commerce (DOC). This was an important step in addressing the issue; however, if we are to have any hope of mitigating MMOD risks in our future space operations, DOC and other departments and agencies, including NASA, will need to take appropriate follow-up actions.

On October 11, 2018, shortly after the Soyuz MS-10 spacecraft was launched from the Baikonur Cosmodrome in Kazakhstan, there was an anomaly during the boost phase, and the launch ascent was aborted, resulting in a ballistic spacecraft landing. The search and rescue team rapidly reached the landing site and reported that the crew was in good condition. Roscosmos convened an investigation board and concluded that the mishap was due to a deformed sensor in a system that controls the separation of a first-stage strap-on rocket booster. Because NASA has long-established relationships and defined processes to work with Roscosmos in cases such as this, NASA was confident that it would be able to gain the transparency required to understand the investigation details and to work with Roscosmos on forward options for ISS operations. The Panel believes that events like this underscore the importance of having a robust abort system to ensure crew survival.

C. End of Life/Deorbit Planning

With regard to the ISS Deorbit Strategy and Contingency Action Plan, NASA has received and is continuing to assess information from Roscosmos and is requesting International Partner concurrence with existing documentation through the Cosmos Change Request review system. Some of the open work includes Functional Cargo Block propellant maintenance at vacuum; software updates to enable reentry and burn functionality; ISS guidance, navigation, and control studies; ISS survivability at vacuum; and development of draft operations products for regular and contingency deorbit. Although progress has been slower than desired, the effort is definitely moving forward, and the Panel is encouraged by the progress being made.

D. Plan to Phase-out Funding/Commercialization of Low-Earth Orbit

Currently, there is considerable debate on what the ISS lifetime should be and how to transition to a different platform to provide a persistent LEO presence. There is general agreement that the U.S. has an ongoing need for capabilities in LEO and that there should not be a "gap" in capabilities after ISS is no longer available. NASA is currently soliciting ideas from industry on what specific capabilities are appropriate post-ISS. The questions NASA is trying to answer are: What products and services would industry like to offer, and what is the business plan that would enable those products and services to be delivered in a reasonable and cost-effective way? The goal is for private industry to provide these capabilities and for NASA to serve as one of many customers rather than the only customer. This would produce benefits not only for NASA and the space industry, but for the space program as a whole.

Recognizing that there are many different viewpoints on what commercialization of LEO should look like, the Panel sees a continuing need for a NASA presence in LEO to conduct operations that would reduce the risk for future space exploration. The maintenance of appropriate expertise will also be key. Turning LEO over to the commercial sector would seem to be a reasonable next step, allowing NASA to focus on deep-space exploration. This approach would also provide a marketplace for commercial entities to sell services. Once NASA has received and evaluated potential options and decided on the most promising approach, it will be important for NASA to develop and communicate its implementation plan as soon as possible to enable a smooth transition. Integral to development of that plan will be the need to understand what ISS research needs to be accomplished prior to Moon and Mars operations, both in human health and in system reliability.

V. Aeronautics and Air Operations

A. Overview

During 2018, two Panel members had the opportunity to attend IAOP meetings, engage in safety discussions with the Aircraft Advisory Committee, and participate in the Inter-center Aircraft Operations Review at AFRC. Observations of safety processes within NASA's Aircraft Management Division (AMD) were very positive overall. These observation opportunities provided clear, tangible evidence of a mature safety program and a high-functioning safety culture within NASA AMD. As a direct result of this effective safety program, IAOP risk assessment processes have self-identified some risk areas within NASA flight operations that we feel are worthy of Agency-level focus.

B. NASA Aircraft Management Information System

As stated in the Panel's 2017 Annual Report, the NASA Aircraft Management Information System (NAMIS) sustainment continues to be an ASAP focus area. NAMIS remains the single information system of record for managing Agency aviation operations. It is required for day-to-day execution of aviation activities and includes software modules that ensure proper documentation of both manned and unmanned aircraft airworthiness, aircrew readiness, technical publications, as well as aviation parts inventory and logistics tracking. NAMIS software must be modified periodically, not only to account for routine software security and operating system upgrades, but also to reflect policy and procedural changes. NAMIS operating cost is allocated primarily to the human resources needed to ensure 24/7 system access and to conduct emergent software changes. Budget-driven manpower constraints necessitate prioritization of emergent software changes via the Configuration Control Board process. This process was developed by the NAMIS Program Management team to ensure critical, safety-of-flight software functions are given priority over less critical changes. The Panel commends the NAMIS team for managing changes in this manner in the face of a resource-constrained environment. Budget stability over the long term—at a level that allows NAMIS Program Managers to maintain sufficient manpower resources to respond to emergent changes and improve software functionality—is a critically important safety item. NAMIS is required to support almost every facet of Agency flight operations, and without it functioning as designed, safely operating aircraft would present considerable challenges. In previous years, annual budgetary funding constraints and year-end budget reductions have threatened to impede NAMIS functionality. The Panel will continue to interact with AMD and maintain a watchful eye on NAMIS funding stability and overall NAMIS readiness. We remain concerned that budgetary perturbations could impact NAMIS functionality resulting in workarounds that could lead to lapses in airworthiness and aircrew readiness documentation.

C. Contract Air Services

During discussions with the IAOP, Panel members noted that there has been an increase in Contract Air Service (CAS) flight operations, primarily supporting various NASA Earth science missions. Table 1 shows a total of 5,045 hours were flown during 2017 for the Airborne Science Program, with 1,688 of the 5,045 hours (33 percent) as CAS.

These CAS flights—conducted for NASA primarily on contracted aircraft by civilian contracted aircrew—operate under the provisions of Title 49 U.S.C. § 40102(a)(41) "Public Aircraft Operations" (PAO). NASA missions flown under the provisions of PAO, for all intents and purposes, are operating

TABLE 1. Airborne Science Program Flight Hours Flown During 2017, with 5,045 Total Flight Hours Flown and 1,688 of those hours flown by CAS

Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hours Flown
DC-8[1]	15	6	0	6	595.8
ER-2[1]	42	24	2	17	309.1
P-3[1]	6	2	0	2	484.7
WB-57[2]	2	1	0	1	90.3
Twin Otter[2]	9	5	1	4	170
B-200[2]	11	7	1	6	443.7
Global Hawk[1]	6	3	0	2	159.1
T-34[2]	1	1	0	0	0
C-130 Hercules[2]	4	4	1	2	225.7
C-20A (G-III) - AFRC[1]	23	20	2	11	362
C-23 Sherpa[2]	4	3	0	3	94.8
Dragon Eye[2]	3	1	0	1	4.5
Falcon-HU-25[2]	1	1	0	1	39.5
G-III-JSC[2]	28	21	1	15	376.9
Ikhana[2]	1	0	0	0	0
SIERRA[2]	3	0	0	0	0
Other[3]	45	30	2	22	1688.4
TOTALS	**203**	**129**	**10**	**93**	**5044.5**

1 ASP Supported Aircraft include: DC-8, P-3, ER-2, C-20A, and the Global Hawk.

2 These aircraft are NASA owned aircraft not subsidized by the Airborne Science Program B-200 (B-200 – AFRC, B-200 – LARC, B-200 - UC-12B), Twin Otter (Twin Otter GRC, Twin Otter JPL).

3 Non-NASA contract aircraft include: A90 Dynamic Aviation, A90 King Air, Aeroscout, Alphajet, Aurora Centaur (DA-42) Aircraft, B-200 - King Air - Dynamic Aviation, BlackSwift Tempest; SuperSwift sUAS, Caravan, CIRPAS Twin Otter, Piper Cherokee/King Air, DA King Air, DC-3, DC-3 Bassler, Dragon Eye, Dynamic Aviation - King Air, Dynamic Aviation B-200T, JSC G-V, Kenn Borek Air LTD, King Air B-200, Mooney, NRL P-3, Tarot Hexacopter, Tempus G-IV, Twin Cessna 310J, Twin Otter – SGL, Twin Otter International, UAS.

de facto as NASA aircraft. For example, NASA as the contracting agency assumes sole responsibility for oversight of any flight in direct support of the contracted mission. In the event of a mishap, NASA, rather than the National Transportation Safety Board or FAA, would be responsible for mishap investigation. FAA regulations specify: *The government entity conducting the PAO is responsible for oversight of the operation, including aircraft airworthiness and any operational requirements imposed by the government entity. The government agency contracting for the service assumes the responsibility for oversight of a PAO.* In terms of contract requirements, the Department of Defense generally requires CAS contracts to be written to conform to FAA/Federal Aviation Regulation (FAR) Part 135 requirements, a standard that requires a higher level of aircraft and aircrew certification. While CAS operations under FAR Part 91 could very well be appropriate for some basic NASA missions, overall mission complexity and risk should be considered as a guiding factor when defining the requirements for CAS contracts. AMD has formed a working group tasked to develop a comprehensive CAS/PAO oversight plan. This IAOP Tiger Team has made recommendations and is developing Agency-level standards for managing the acquisition and oversight of CAS. An updated NPR 7900.3D now incorporates a CAS Chapter, which provides some basic guidance to Centers for the standardization of CAS. Nevertheless, the IAOP safety process and the Aircraft Management Division (AMD) have identified CAS as a top Agency-level safety risk. In large part, this assessment of elevated risk is related to lack of manpower, expertise, and clear pol-icy guidance on CAS procurement, conduct, and oversight. At present, Center Aviation Safety Officers and Quality Assurance maintenance personnel have assumed oversight responsibility. This is in addition to their primary assigned duties as center aviation safety program managers. While CAS may appear to offer attractive advantages such as rapid deployment, flexibility, and cost effectiveness for some Earth sci-ence missions, the actual cost is inevitably higher than contract bottom-line cost. Manpower costs for proper contract oversight are just one example of some of the hidden or displaced costs. The Panel views CAS/PAO as a risk exposure area that should be evaluated more carefully.

D. New Aviation Horizons

Last year, the ASAP Annual Report outlined the nascent New Aviation Horizon Program and discussed the Agency's return to more active experimental test flight operations and the risks associated with this increase in "X-plane" flight. Considering this year's award of the Low Boom Flight Demonstrator contract, the ARMD is now poised to expand operations in this demanding arena. The Panel once again emphasizes the importance of a measured

FIGURE 11. Artist conception of the X-59 QueSST Low Boom Supersonic Flight Demonstrator Aircraft

approach to moving into this challenging experimental realm. There will undoubtedly be some "unknown-unknowns" discovered along the way. Risks associated with exploring the transonic/supersonic flight envelope of advanced technology demonstrator aircraft must be mitigated to an acceptable level, not only for the test flight personnel, but also for the civilian population over which they may fly. We are pleased to see marked progress in the area of advanced aeronautical research.

E. Aircraft Fleet

NASA operates a diverse fleet of one-of-a-kind, older aircraft that presents some unique sustainment challenges. For example, AFRC's DC-8 Airborne Science Laboratory is one of only six DC-8 aircraft operating worldwide, and economical spares procurement may become a major issue in the future. While there are no indications that NASA is operating aircraft beyond their fatigue life-safety margins, operating this type of aircraft does not come without unanticipated failure risk. Going forward, AMD will need to make strategic decisions regarding long-term fleet sustainment and inventory. Considering the growing use of CAS, NASA should closely examine the desired or required aircraft capabilities to be maintained in their portfolio; e.g., supersonic, high-altitude, long-range, large payload capacity, etc.

FIGURE 12. AFRC's DC-8 Airborne Science Laboratory

F. Unmanned Aircraft System Operations

The Panel has noted excellent progress in unmanned aircraft system (UAS) operations and procurement oversight. AMD has codified processes in place that ensure effective safety and oversight of all classes of UAS operations across the Agency. While this is an area that warrants continued watch, AMD has made great strides towards ensuring safety of Agency UAS operations, including alignment of NASA directives with FAA/FAR Part 107.41 requirements and limitations for airworthiness, as well as codifying aircrew training and operational flight approval processes.

G. Safety Process Observation

As noted earlier, Panel members participated in the Inter-center Aircraft Operational Safety Review at AFRC in September 2018. During this flight operations safety review, we were pleased to see that the IAOP safety assurance process goes much deeper than a programmatic, paper-checklist-driven compliance assessment. In addition to determining whether the organization is meeting the programmatic safety policy requirements, the assessment attempts to measure how those policies actually translate into positive safety behavior in day-to-day operations. Through direct observation and participation in processes, this holistic assessment method is designed to expose the normal behavior and prevalent culture of the organization. The Panel commends AMD for its efforts related to the Interagency Aircraft Operations Review. We believe this safety assessment process serves as a model "best practice" for effective safety assessment.

VI. Enterprise Protection

Throughout 2018, the ASAP monitored NASA's progress on its Enterprise Protection Program (EPP) and related risk management activities. NASA continues to receive pressure from both the Administration (through a May 2017 Presidential Executive Order) and—through numerous audits—the NASA Office of Inspector General (OIG) to broadly account for NASA risk posture across the security enterprise. To NASA's credit, Agency leadership has demonstrated awareness of the risks. In 2018, a few small steps were taken toward an improved risk posture for the physical, corporate, and mission layers of the enterprise. NASA has focused its efforts this year on identifying threats, managing governance structures, and tightening the collaboration links between various risk stakeholders within NASA. NASA has improved threat information sharing among key management members, but the implementation of effective risk reduction practices has generally remained a topic for future work. From our perspective, the implementation of broader risk reduction measures and how such measures are implemented through governance will continue to be a watch item in 2019.

The NASA EPP made some progress in 2018. First, after the announced retirement of the original Principal Advisor for Enterprise Protection, his replacement was in position at the end of 2017 and has spent much of 2018 building a foundation for continued success, including the hiring of a deputy. Second, the Presidential Executive Order, "Strengthening the Cybersecurity of Federal Networks and Critical Infrastructure" (May 11, 2017), appears to have energized the cybersecurity culture within NASA. The NASA Chief Information Officer (CIO) has demonstrated excellent leadership in addressing many of the stated shortfalls that were noted in NASA's response to the Executive Order and in several NASA OIG reports. Third, NASA has strengthened focus on addressing the threats to mission systems and is working with the Human Exploration and Operations programs to export their threat

reduction model to other NASA missions. However, as mentioned in the 2017 ASAP Annual Report, NASA continues to receive reports and audits on many elements of Enterprise Protection (e.g., cybersecurity, governance for mission and institutional information technology systems), and remains challenged to address the volume of findings, some of which have repeated over several years.

The ASAP Panel members viewed a drawing that was included in NASA's response to the Executive Order in 2017 as the best representation of how NASA thinks the Enterprise must be protected. In 2017, the Panel was very impressed with how NASA chose to define a framework to describe the full range of the Enterprise. Since then, we have referenced this framework to garner deeper understanding of how NASA is taking action to protect the defined Enterprise. In 2018, the ASAP had two structured engagements with NASA about forward progress. One engagement occurred at our first 2018 quarterly meeting at MSFC. At that meeting, the focus was on introducing the new Principal Advisor for Enterprise Protection, providing an update on EPP governance-related efforts, and conveying a minor example of threat coordination. In addition, the Office of the CIO gave a very comprehensive update on cybersecurity. The second structured engagement occurred during the fourth quarterly meeting at JSC. It was centered on a threat mitigation presentation by personnel from the HEO program (intended as a model that will broaden to other mission programs), along with a short update on EPP governance. However, this engagement occurred in a classified environment and was not observed by most ASAP Panel members (although much of the material covered was unclassified). The ASAP had requested specific EPP-related updates throughout the year, including the scheduling of a special session in August (subsequently cancelled by NASA). However, we have received less information than we would like. What has been received has been helpful, but not sufficient, to aid our understanding on NASA's progress in this critical area and to provide a fair assessment on the EPP's success.

As the Panel stated in its 2017 Annual Report, it is apparent that NASA's work in the area of Enterprise Protection is demonstrating some progress. For example, NASA has created an interim directive related to Enterprise Protection for the Agency and is maturing the Enterprise Protection Board through four meetings of the Board in 2018. In response to the Presidential Executive Order and other pressures, the Office of the CIO has moved aggressively toward results-oriented outcomes. However, as best as we can assess, NASA's overall progress toward enterprise risk reduction for physical, corporate, and mission layers still requires governance, language, rule sets, budget alignments, clarity of authorities, and much more to actually achieve a "sea change" in risk-reducing behaviors across the Enterprise. There may be more concrete progress accomplished by NASA in 2018, but we have not yet had the opportunity to fully understand how Enterprise risk reduction is being implemented in practice. Without further understanding, it is difficult to know whether the budget held by implementing organizations devoted to Enterprise Protection is adequate, the integration across NASA is effective, and the security culture is improving.

Although the Panel has not seen sufficient evidence of a broadly supported EPP, the Principal Advisor and the EPP did make progress in addressing our very specific concern: implementing a policy that ensures that appropriate security clearances levels are attained and maintained for those personnel—including the appropriate program managers—who have a role in managing Enterprise risk. In 2016, we formulated Recommendation (2016-04-01) on Asset Protection – Security Clearance Policy.

> The ASAP recommends that NASA make it a matter of policy that priority is given to obtaining the appropriate level of security clearance for all personnel essential to implementing the Enterprise Protection Program, including the appropriate program managers.

The ASAP received a progress report late in 2018 about NASA's improved security clearance procedures. The report indicated that security clearance management has the appropriate attention at the most senior leadership level, and a fairly robust process exists to capture the requirements for determining whether a position should be encumbered with a security clearance requirement. NASA intends to accomplish an Agency-wide review by December 2018. We look forward to a status report early in 2019.

VII. Safety Culture

A. Importance of Safety Culture

In the Panel's 2017 Annual Report, we reported that the safety culture within NASA would be a focus area in 2018.

A strong safety culture within NASA is essential. When a safety culture is healthy, people at all levels of the organization are comfortable raising safety issues, voicing dissenting opinions, and knowing that appropriate resources and expertise will be applied to investigate and address safety concerns. An organization with a strong safety culture learns from process escapes, "near misses," and successes, and shares important information with all relevant entities. Safety practices are "owned" by the workforce, and there is not a "check the box" mentality.

Professor Patrick Hudson of the Centre for Safety Research at Leiden University in The Netherlands developed a frequently cited model of safety culture maturity. As illustrated in Figure 13, safety cultures progress through evolutionary stages. In the most mature, or "generative," safety cultures, safe behavior is fully integrated into all activities. The Panel's goal is to see NASA demonstrate a "generative" safety culture. At this point, we do not see clear evidence that NASA's safety culture is operating at this stage in all areas. NASA's Safety Audit Process should be thoroughly evaluating its programs to ascertain the appropriate metrics that would provide this evidence and encouraging practices such as peer review, best practice benchmarking, and physical audit of workplace activities to ensure safety.

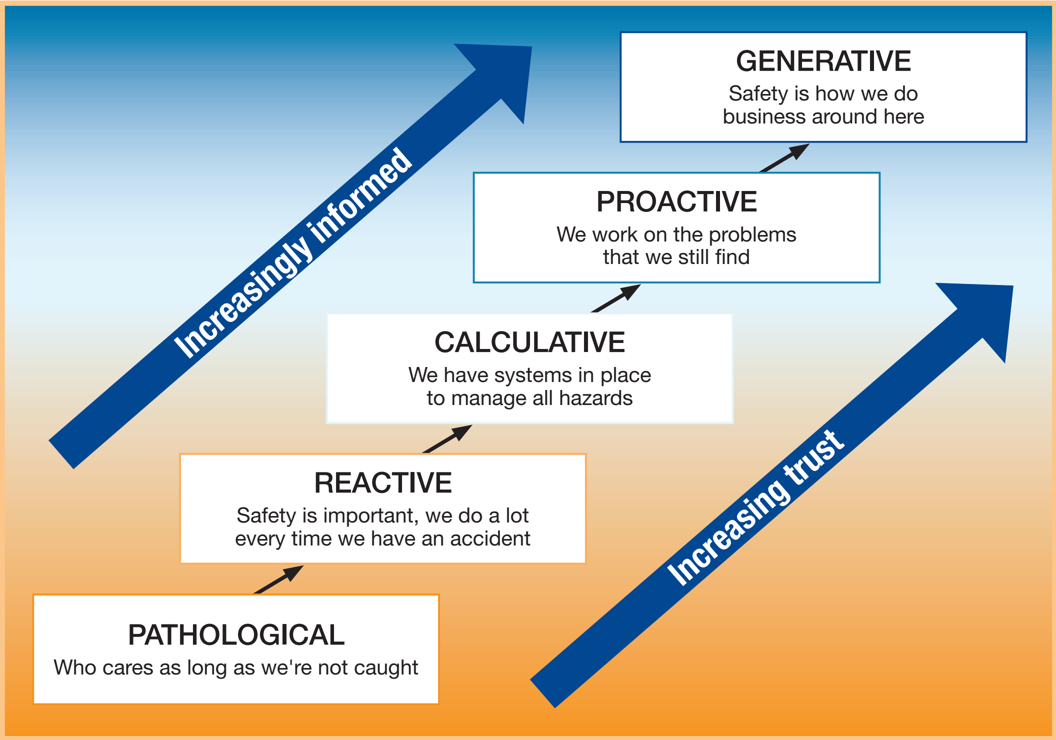

FIGURE 13. Hudson's Evolutionary Model of Safety Culture

B. NASA's Safety Audit Process

The Safety Audit Process should begin at the program design stage and capture metrics such as the number of safety concerns raised, how many were resolved through the hazard control hierarchy, and how many were elevated to senior management levels for acceptance of residual risk. Appropriate metrics include the number of dissenting opinions raised; the number of quality escapes that resulted or could have resulted in near misses or incidents; and the number of actual mishaps, incidents, and close calls.

The Panel previously visited the NASA Safety Center to gain insight into the Safety Audit Process. We asked how the Safety Audit Process ascertained the health of NASA's safety culture. NASA's responses have not mitigated our concerns. For example, surveys were conducted which resulted in no identifiable safety issues, but at least some members of the NASA Aviation Safety community that we spoke with (a community that practices a rigorous aviation safety program on a daily basis) were not aware of the safety surveys that were being conducted. We regard this as evidence that the current Safety Audit Process has not achieved full coverage of system safety practice within NASA.

Recognizing that NASA needed to gather data that would provide indications of the heath of its safety culture, the Panel made the following recommendation (2017-02-01) on the Schedule and Cycle of Safety Audits:

> NASA should establish, prioritize, resource, and implement a rigorous schedule of audits, executed by the Office of Safety and Mission Assurance (OSMA) and conducted at the Center level, to ensure that documented safety requirements, processes, and procedures are consistently applied across the Agency.

OSMA responded, reporting that they conducted a survey of targeted SMA engineering disciplines, including System Safety. In 2018, the Panel heard updates on the progress of the survey, as well as details on a more focused Safety Culture Survey, still in progress. While we appreciate these efforts, we remain concerned that these surveys—and the Safety Audit Process in general—do not ensure effective implementation of both workplace and system safety-related practices and processes. At the Panel's second quarterly public meeting at KSC in May 2018, we proposed the following revised Recommendation (2018-02-01) with a revised title—NASA Safety Assurance Process Scope and Quality:

> NASA Safety and Mission Assurance should have a coordinated, in-depth system of safety assurance tools and processes to verify effective programmatic safety compliance, system safety practices, safety process function, safety culture, and overall safety posture at all levels of the organization.

C. The Technical Authority Role in Safety Culture

For many years, the Panel has championed the TA role in contributing to risk reduction efforts. The TA process was created to establish a more robust system of checks and balances and to provide independent program oversight in support of safety and mission success. TA is delegated from the Administrator and includes oversight roles for three officials: the Chief, Safety and Mission Assurance; the Chief Engineer; and the Chief Health and Medical Officer. The Panel learned much about the TA role and resolution of dissenting opinions in 2018. We were particularly interested in how the proper decision-making level is determined. While it is important to preserve appeal authority to the highest levels of Agency management, we believe that dissenting opinions are best addressed at the program TA level. This improves the velocity of decision making and enhances the overall safety culture through accountability at the program level. We will continue to review the way dissenting opinions are resolved.

D. Improving NASA's Safety Culture

The Panel will be paying attention to the safety culture at NASA in the coming years. The revised Safety Audit Recommendation (2018-02-01) summarizes the steps and improvements that should occur to help raise the NASA safety culture through the evolutionary stages to the highest levels. NASA should clearly establish and thoroughly track appropriate metrics that indicate the health of the safety culture and enhance the Safety Audit Process. As noted in Section V above, NASA's aircraft flight operations and the IAOP safety assessment process serves as a model "best practice" for effective determination of safety culture and safety behavior. We recognize that the IAOP safety assessment process is applied in an operational environment. However, we believe that practices exemplified in the IAOP safety assessment process, such as peer review and physical audit of safety practice at the worksite, may yield great dividends in developmental programs as well.

VIII. Summary

Eleven topic areas of continuing interest to the ASAP are summarized below. They have been broken out to focus attention on individual issues that the Panel feels are worthy of note.

Topics	2018 Assessment
Commercial Crew Flight Readiness	There are remaining technical challenges for both providers that potentially impact the risk posture and certification process. NASA needs to confirm and communicate clearly its expectations for what needs to be demonstrated on the full-scale flight testing before crewed operations.
Human Space Flight Mishap Response Procedures	Language in the NASA Authorization Act of 2005 requiring a Presidential Commission for independent investigations must be reviewed and revised, especially as we are on the cusp of reinitiating U.S. launch of our astronauts.
Continuing U.S. Presence on International Space Station (ISS)	Potential delays in Commercial Crew Program (CCP) flights put NASA at risk for a disruption in U.S. presence on the ISS. Attempting to mitigate this issue may lead to greater risk acceptance by NASA via a compressed program schedule. To counter the safety risks of schedule pressure, NASA should consider contingency plans, including all available transportation options, for continuity of operations.
Micrometeoroid and Orbital Debris (MMOD) Risk	MMOD remains a dominant safety risk for CCP, ESD, and ISS. Space Policy Directive 3 focused on this hazard, but meaningful actions resulting from that Directive are essential.
Exploration Systems Development (ESD) Challenges/Issues	Core stage manufacture and qualification tests continue to pace the schedule. Software validation and verification remain on the critical path. Risk integration at the system level needs to ensure that the combined risk posture is properly assessed. Exploration Mission (EM)-1 heat shield data acquisition is an essential element to assuring crew safety for EM-2. Environmental Control and Life Support System (ECLSS) development planning and qualification must be fully completed prior to crew flight beyond LEO. The items required on EM-1 for qualification on EM-2 must be definitively stipulated.
European Service Module (ESM) Propulsion System	ESM propulsion in terms of a serial vs. parallel system represents considerable residual risk. Prior program commitment was to move to a parallel system past EM-3. The decision to remain with the serial system needs to be fully investigated in regard to the level of residual risk to deep-space missions before final decision is made.
ISS Lifetime/Need for Low-Earth Orbit (LEO) Platform	NASA has an ongoing need for a platform in LEO to serve as a testbed for long-duration technical development and human research. To avoid a gap in capabilities, NASA should evaluate available options as soon as possible and decide on and communicate the most promising approaches.
NASA Aircraft Management Information System (NAMIS)	NAMIS is essential for safe execution of aviation activities. Budgetary impacts could lead to lapses in airworthiness and aircrew readiness.
Contract Air Services (CAS) Operations and Oversight	CAS operations has been identified as a top Agency-level safety risk directly related to lack of manpower, expertise, and clear policy guidance on CAS conduct of operations and contractor oversight.
Enterprise Protection	NASA has made progress, but the approach toward enterprise risk reduction for physical, corporate, and mission layers still requires considerable maturation (e.g., improved governance) to achieve a "sea change" in risk-reducing behaviors across the Enterprise.
NASA Safety Culture	There is no clear evidence that NASA's safety culture exists at a "generative" stage (fully integrated into everything the Agency does) in all areas. NASA's Safety Audit Process should be thoroughly evaluating its programs to provide this evidence. Safety audits should begin at the program design stage and capture metrics to determine the health of NASA's safety culture.

APPENDIX A

Summary and Status of Aerospace Safety Advisory Panel (ASAP) Open Recommendations

2018 Recommendations[1]

2018-04-01

Required Actions for Crewed Flight Test Risk Reduction: NASA should confirm and then clearly communicate the required content and configuration for the upcoming CCP test flights-Demo-1 and Orbital Flight Test (OFT)-specifically, those items that must be successfully demonstrated prior to the first crewed flights.

OPEN NASA response not provided at time of ASAP Annual Report 2018 printing.

2018-04-02

Action to Ensure U.S. Access to the International Space Station Given Commercial Crew Program Schedule Risk: Due to the potential for delays in the schedule for the first Commercial Crew Program (CCP) flights with crew, senior NASA leadership should work with the Administration and the Congress to guarantee continuing access to ISS for U.S. crew members until such time that U.S. capability to deliver crew to ISS is established.

OPEN NASA response not provided at time of ASAP Annual Report 2018 printing.

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1 *Note on colors:* Red highlights what the ASAP considers to be a long-standing concern or an issue that has not yet been adequately addressed by NASA, or that there is no identified resolution. Yellow highlights an important ASAP concern or issue that we are not confident is being addressed adequately by NASA, or where a resolution has been identified but does not yet have a defined implementation plan. Green indicates a positive aspect or concern that is being adequately addressed by NASA but continues to be followed by the Panel.

2018-02-01 (2017-02-01 Revised)

NASA Safety Assurance Process Scope and Quality: NASA Safety and Mission Assurance should have coordinated, in-depth system of safety assurance tools and processes to verify effective programmatic safety compliance, system safety practices, safety process function, safety culture, and overall safety posture at all levels of the organization.

> **OPEN** NASA responded on 8/10/18, concurring with the recommendation which is a revision of ASAP Recommendation 2017-02-01. NASA provided a summary of current and future activities including deep-dives at selected NASA Centers and documentation of its findings and recommendations for an on-going performance-based safety and mission success audit process in a State of Capability report targeted for completion in December 2018. The ASAP will review the report in early 2019.

Open Recommendations from Prior Years

2017-01-01

Practice of System Engineering and Integration (SE&I) Principles by Commercial Crew Providers for Transportation Services to the International Space Station (ISS): Panel recommends that NASA require the Commercial Crew providers to produce verifiable evidence of the practice of rigorous, disciplined, and sustained SE&I Principles in support of the NASA Certification and operation of commercial crew transportation services to the ISS.

> **OPEN** NASA responded on 5/22/17, concurring with the recommendation. NASA stated that the Commercial Crew Program (CCP) providers are responsible for ensuring cost-effective system design, realization, operation, and technical management of the systems they are developing to meet a fixed-price contract. Through contract requirement, deliverables, and insight, CCP is able to verify and/or validate that SE&I principles are followed to assure the proper management of risks, requirements, interfaces, configuration, and technical data throughout the system life cycle. Boeing is utilizing traditional systems engineering practices. In 2018, the Panel received a series of briefs by NASA and SpaceX detailing and illustrating the comprehensive internal tool developed that includes traceability from component design drawings and related design notes all the way through to production procedures, automation of promulgating design changes through other appropriate products. Widely in use, the tool allows the company to document, easily update, and immediately understand impacts of design changes and manufacturing anomalies. The ASAP is

satisfied with what it has learned regarding the SE&I approaches by both companies to date and will continue to monitor the SE&I practices throughout the development and certification process.

2016-04-01

Asset Protection—Security Clearance Policy: NASA should make it a matter of policy that priority is given to obtaining the appropriate level of security clearance for all personnel essential to implementing the Enterprise Protection Program, including the appropriate program managers.

OPEN NASA responded on 1/17/17, concurring with the recommendation. NASA was establishing clearance requirements within the governance management system of the Enterprise Protection Program (EPP) and is reviewing all position descriptions and compliances accordingly. The Panel was briefed on the EPP in 2018 regarding NASA's improved security clearance procedure, and it appears that a fairly robust process exists. NASA intends to accomplish an Agency-wide review by December 2018 and will provide a status report in early 2019.

2015-05-02

Human Space Flight Mishap Response Procedure: The Authorization language should be reviewed with today's systems in mind. Also, more details appear appropriate for the NASA implementation document. These details would include the level of vehicle damage requiring investigation, the temporal issues of when mission phases begin and end, and NASA's oversight role in mishap investigations conducted by its providers, as well as when the need for outside oversight is required. The mishap response procedures should be thought through, documented, and in place well before any actual flights.

OPEN NASA originally responded on 4/31/2016 concurring with the recommendation. The response stated NASA was reaching out to the Federal Aviation Administration (FAA) and the National Transportation Safety Board (NTSB) to jointly develop viable options to revise the Authorization language with today's systems in mind. NASA provided a follow-up response on 3/20/17 in which they provided the results of NASA's assessment of strategy options in the event of a major malfunction or mishap in the Commercial Crew Program (CCP). The ASAP provided a written response on September 8, 2017, followed by subsequent discussions during which the ASAP provided alternate solutions to which NASA provided a third response on 3/15/18. NASA and Congress are still working to establish a satisfactory process to address the concerns previously articulated. The ASAP believes action is now essential as NASA nears the re-establishment of their human launch capability.

2012-01-02

International Space Station (ISS) Deorbit Capability: (1) To assess the urgency of this issue, NASA should develop an estimate of the risk to ground personnel in the event of uncontrolled ISS reentry. (2) NASA should then develop a timeline for development of a controlled reentry capability that can safety deorbit the ISS in the event of foreseeable anomalies.

OPEN NASA originally responded on 5/9/12. The ASAP decided the recommendation would stay open until ISS has a timeline for implementing a deorbit plan and the deorbit plan is in place. HEOMD began working this action when assigned in 2012. There are many aspects to implementing the deorbit plan, including working with International Partners. NASA has received and is continuing to assess information from Roscosmos and is requesting International Partner concurrence with existing documentation. Progress has been slow, but the effort continues to move forward. The Panel is encouraged by the progress being made. ISS will continue to brief the ASAP on a quarterly basis on the status of this recommendation in 2019.

APPENDIX B

2018 Recommendations, NASA Response, and Status; Closure Rationale for Recommendations Closed in 2018

2018 Recommendations, NASA Response, and Status

2018-02-01: NASA Safety Assurance Process Scope and Quality

Finding

In visiting the Centers and the NASA Safety Center (NSC), the Panel found some deficiencies in the audit system—such as system safety—where it became apparent that the workforce was not adhering to policies and procedures, or that policies and procedures were not well understood. While in some cases there was integrity and audit processes, in other areas the NSC did not appear to be auditing at all or auditing infrequently.

The Panel is comfortable that the Office of Safety and Mission Assurance (OSMA) has established, prioritized, and implemented a schedule and periodicity cycle for Center-level safety audits. However, the Panel wants assurance that OSMA has a mechanism in place to verify that the NASA safety policies, processes, and procedures are being followed to ensure effective employee safety, system safety, and program safety. Effective safety assurance involves in-depth assessments of safety culture and first-hand observation of safety processes, in addition to the detailed programmatic compliance checks.

Recommendation (revised)

NASA Safety and Mission Assurance should have a coordinated, in-depth system of safety assurance tools and processes to verify effective programmatic safety compliance, system safety practices, safety process function, safety culture, and overall safety posture at all levels of the organization.

Rationale

The Panel believes this would be an opportunity to take a fresh look across the Agency at what is being done to achieve the goal and measure progress. The Panel emphasized that "effective" means it is not just a paper drill (a checklist)—it should be what is actually being done. The Panel wants positive confirmation that OSMA not only has a policy, but that policy is embraced across the Agency. The Panel is not asking OSMA to create something new, but to ensure that what they have is modified or updated to (1) include system safety; (2) verify that the policies and practices are being followed on a daily basis; and (3) identify any "gaps" that are not being covered.

NASA Response

NASA concurs.

Ongoing Activities: The Office of Safety and Mission Assurance (OSMA) appreciates the opportunity to address the NASA Aerospace Safety Advisory Panel (ASAP) findings and recommendations relative to system safety assurance process scope and quality.

NASA has a very strong safety record. The Agency-level safety policy is steeped in history and informed by lessons from close calls and a broad spectrum of mishaps. Evidence provided below shows that NASA safety policies, processes, and procedures are flowed down to the NASA Centers and Center implementation of that policy is effective. As the ASAP has noted, OSMA has an effective audit program with an appropriate level of periodicity penetrating to a level that assures, both institutionally and programmatically, that OSMA Agency policy and procedures are being followed.

One very impressive piece of evidence resulting from institutional safety policy should be noted. NASA has consistently realized significantly lower employee total case rates for civil service injury relative to all Federal agencies, and it is trending lower each year with a case rate of one case per 400 employees in 2017. This is lower than the NASA Protecting Our Workers and Ensuring Reemployment (POWER) goal and nearly seven times lower than the overall Federal Government case rate. Additionally, NASA has demonstrated a consistent downward trend in Class A, B, and high-visibility mishaps from 21 incidents recorded in 2010 to zero incidents in 2016 with a slight uptick in 2017 to four incidents.

OSMA constantly looks for opportunities to improve on the effectiveness of existing Agency safety policy and to find improved methods to measure the implementation of safety policy across the Agency at all levels. Agency-wide, NASA maintains a safety culture program that focuses on how safety is perceived, valued, and prioritized in organizations. This program measures perceptions across the civil servant and support contractor workforce and enables the NASA Centers and the Agency to identify organizations in which improvements may be needed. OSMA reminds the ASAP, that in addition to the OSMA audit program, OSMA actively participates in the conduct of the Federal Employee Viewpoint Survey (FEVS) and OSMA conducts an Agency-wide employee survey for

Safety Culture with cross pollination between the surveys to compare and contrast the survey results. NASA ranks highest in being the best place to work in the Federal Government. This fact is calculated from the results of employee surveys. OSMA specifically looks at the results of question 17 *(I can disclose a suspected violation of any law, rule or regulation without fear of reprisal)* from the FEVS along with the results of the Safety Culture Survey to assess the safety culture climate across the Agency. Informed by the Chief, OSMA, the NASA Administrator reviews the results of the FEVS and Safety Culture Survey with each Center Director during their annual executive performance review cycle and with this level of leadership emphasis, the safety culture climate at NASA is respected, very strong, and continues to improve.

One of many notable services offered by OSMA, on a request basis, is the conduct of Organizational Safety Assessments (OSAs). In the last 5 years, OSMA has been requested to conduct OSAs tailored to program, project, and organization-specific needs across the Agency. These OSAs have been overwhelmingly productive and value-added for those organizations working to better understand issues, so that efforts can be put in place to improve safety and safety culture for their respective areas of interest.

Within flight projects, NASA has a Safety Mission Assurance Technical Authority (SMA TA) structure that oversees implementation of system safety (and other safety and mission assurance discipline) policy on a day-to-day basis. For human space flight programs, OSMA maintains ongoing awareness of safety activities and concerns via direct interactions between the program-level Chief Safety Officers; Chief, Office of Safety and Mission Assurance; and OSMA staff. For robotic missions, the Expendable Launch Vehicle (ELV) Payload Safety Program ensures that the implementation of system safety requirements is evaluated by independent reviewers resulting in a certification by the OSMA-delegated ELV Payload Safety Manager.

Additionally, over the past several years, OSMA has been evolving its approach to system safety and mission success (SMS), as evidenced in documents such as the two-volume NASA System Safety Handbook and the white paper, "Towards an Integrated Safety & Mission Success Framework." OSMA has laid a foundation for evolving the treatment of SMS within its directives in a manner that is consistent with the ASAP recommendation. NASA has begun development of "NASA Procedural Requirements (NPR) for the Safety and Mission Success of Spaceflight Programs and Projects" that will implement the SMS framework by specifying SMS-related roles and responsibilities for program/project managers and SMA TAs relevant to the design, development, realization, and operation of spaceflight systems. The focus of the NPR will be on the achievement, by programs and projects, of explicit SMS performance objectives at the system level and the development of assurance cases on the part of formally designated risk acceptors that the stated SMS objectives have indeed been met or are on track for being met.

Current/Future Activities: In addition to these ongoing processes, based on the original ASAP recommendation (2017-02-01) and always seeking to identify any gaps, NASA initiated a study to assess the current state of system safety, mission success, and risk management practices. Objectives of the study include the comparison of practices and expectations in the areas of planning, requirements development, analysis, decision-making, performance trending and assurance, as well as the identification of highly effective and innovative practices and gaps where existing policy, training, and guidance can be improved. Following a survey of over 100 practitioners, project and engineering managers, and members of the SMA TA chain, requirements flow-down assessments and "deep-dive" NASA Center visits are ongoing. The requirements flow-down assessments and deep-dive visits will provide NASA with insight regarding the state of practice and serve as trial applications of performance-based audit methods that may be used to enhance the existing audit and assessment program by expanding its coverage to include system safety, mission success, and risk management. Enhancements could take the form of expanding Interim Center Assessments to include peer assessments of system safety (and other discipline) activities across the NASA Centers.

Plans for the study were briefed to ASAP in February 2018. NASA intends to complete deep-dives at selected NASA Centers and document its findings and recommendations for an ongoing performance-based safety and mission success audit process in a State of the Capability report. Completion is currently targeted for December 2018.

Status

NASA concurred with the recommendation, which is a revision of ASAP Recommendation 2017-02-01. NASA provided a summary of current and future activities including deep-dives at selected NASA Centers and documentation of its findings and recommendations for an on-going performance-based safety and mission success audit process in a State of Capability report targeted for completion in December 2018. The ASAP will review the report in early 2019.

2018-04-01: Required Actions for Crewed Flight Test Risk Reduction

Findings

There are serious challenges to the current launch schedules for both SpaceX and Boeing. For SpaceX, one challenge is the lack of final resolution of the composite overwrapped pressure vessel (COPV) failures, which are generally considered to have been involved in a launch pad accident and which affect the total safety of the "load-and-go" launch concept. In addition to this issue, recent parachute performance, both during the CCP qualification testing regimen and during the resupply contract, indicates potential problems with parachute designs. A potential redesign, which may be required, would drive a requirement for additional qual and certification testing. The Boeing program also holds key risk items, some of which have emerged during the qual test program; specifically: parachutes, launch abort engine hot fire testing, and pyrotechnic separation bolt initiator device qual failures. The burndown curve of certification products remains fairly steep for verification and validation (V&V), and much work is ahead. Schedule pressures and the desire to launch pose a potential for the uncrewed test flights to occur without all the critical content to fulfill the role of risk reduction for crewed flight.

Recommendation

NASA should confirm and then clearly communicate the required content and configuration for the upcoming CCP test flights—Demo-1 and Orbital Flight Test (OFT)—specifically, those items that must be successfully demonstrated prior to the first crewed flights.

Rationale

Despite a desire to launch the uncrewed test flights (Demo-1 and OFT) as soon as feasible, it is important to keep in mind that the primary purpose of those flights is to fly the vehicles in a configuration as close as possible to the first crewed flights in order to reduce risk. If content important to that purpose is not flown in a test that essentially duplicates the conditions of the first crewed flights, uncertainty is increased, and safety could be compromised.

NASA Response

At the time the 2018 Annual Report went to print, NASA had not yet responded to this recommendation, which was presented to the NASA Administrator in the Quarterly Meeting Minutes dated October 23, 2018.

2018-04-02: Action to Ensure U.S. Access to the International Space Station Given Commercial Crew Program Schedule Risk

Findings

As outlined in the findings for Recommendation 2018-04-01, serious technical difficulties and challenges pose considerable risk to both providers' schedules for crew transportation to the ISS in CY 2019. Currently, there are no Soyuz seats available for U.S. crew after 2019.

Recommendation

Due to the potential for delays in the schedule for the first CCP flights with crew, senior NASA leadership should work with the Administration and the Congress to guarantee continuing access to ISS for U.S. crew members until such time that U.S. capability to deliver crew to ISS is established.

Rationale

Without commercial crew flights in 2019, the U.S. will have no other means of access to the ISS unless other options are identified and approved, or existing constraints are waived. Although they may not be needed, having back-up plans in place for such contingencies could be extremely important if the CCP flights are significantly delayed.

NASA Response

At the time the 2018 Annual Report went to print, NASA had not yet responded to this recommendation, which was presented to the NASA Administrator in the Quarterly Meeting Minutes dated October 23, 2018.

Closure Rationale for Recommendations Closed in 2018

2017-02-01

Schedule and Cycle of Safety Audits: NASA should establish, prioritize, resource, and implement a rigorous schedule of audits, executed by Office of Safety and Mission Assurance (OSMA) and conducted at the Center level, to ensure that documented safety requirements, processes, and procedures are consistently applied across the Agency.

CLOSED NASA responded on 8/29/17, concurring with the recommendation and provided a presentation at the 4th Quarterly Meeting of 2017. OSMA had prepared a survey of targeted SMA engineering disciplines, including System Safety, and would administer it from November 2017 through January 2018.

After reviewing the information received in 2018, the Panel was comfortable that OSMA has established, prioritized, and implemented a schedule and periodicity cycle for Center-level safety audits. The Panel however wanted assurance that OSMA has a mechanism in place to verify that the NASA safety policies, processes and procedures are being followed to ensure effective employee, system and program safety. The Panel closed this recommendation and opened a revised version, reference: Recommendation 2018-02-01.

2014-01-01

Radiation Risk Decision on Deep Space Mission: The ASAP recommends that (1) NASA continue to seek mitigations for the radiation risk and (2) establish an appropriate decision milestone point by which to determine acceptability for this risk to inform the decision about a deep space mission. This risk choice should be made before NASA decides to go forward with the investment in a future long-term mission.

CLOSED NASA originally responded on 4/24/14 concurring with the recommendation. The Office of the Chief Health and Medical Officer (OCHMO) briefed the NASA implementation plan to the recommendations in the Institute of Medicine (IOM) Study to the ASAP on 10/28/14 at the 4th Quarterly ASAP meeting and received subsequent briefings annually. Progress continues to be made in policy and guidelines. Although the Panel remains concerned about radiation risk, they believe that NASA is addressing the risk in a manner that allows them to maximize risk mitigation options.

2014-AR-05

Processes for Managing Risk with Clear Accountability: NASA should consistently provide formal versus ad hoc processes for managing risk with clear accountability.

CLOSED NASA originally responded on 7/22/14, concurring with the recommendation and provided an updated response on 1/22/15. OSMA released an interim directive, NID 800.4, Agency Risk Management Procedural Requirements in September 2016, and subsequently released the directive, NASA Procedural Requirement (NPR) 8000.4B on December 6, 2017. The NPR has met the ASAP concerns on management of risk, allowing the closure of this recommendation. The ASAP plans to continue monitoring the effective implementation of the NPR in the future.

APPENDIX C

ASAP Members and Staff

Aerospace Safety Advisory Panel Members

Dr. Patricia Sanders

- Chair, Aerospace Safety Advisory Panel
- Independent Aerospace Consultant
- Former Executive Director of the Missile Defense Agency (MDA)
- Former Director, Test, Systems Engineering, and Evaluation, Office of the Secretary of Defense
- Former Director of Analysis for the U.S. Space Command

Dr. Patricia Sanders is now an independent aerospace consultant after having been a Senior Executive with the Department of Defense (DOD) and retiring from the Federal Government after 34 years of service with experience in the management of complex technical programs, leadership of large and diverse organizations, and development and execution of policy at the DOD level.

Dr. Sanders retired from Government service in 2008 as the Executive Director of the Missile Defense Agency (MDA). She was the senior civilian in the Agency responsible for its management and operations, safety and quality control, strategic planning, legislative affairs, external communication, and all issues related to worldwide personnel administration and development. Previously, she had been the System Executive Officer and Deputy Director for Integration of MDA, managing program content, schedule, cost, and technical performance for the Agency's $9 billion per year program of work.

After teaching for Boise State University and the University of Utah, Dr. Sanders began her national security career with the U.S. Army in Germany in 1974. She progressed through a number of challenging positions including management of several Defense acquisition programs; positions with the Air Force Operational Test Center in space system and aircraft avionics testing; Chief Scientist for the Command, Control, and Communications Countermeasures Joint Test Force; and Director of Analysis for the U.S. Space Command.

In 1989, Dr. Sanders moved to the National Capital Area to assume the first of a number of staff positions within the Office of the Secretary of Defense, culminating with service as the Director of Test, Systems Engineering, and Evaluation. She joined the missile defense community in 1998 and participated in the establishment of the MDA, was responsible for creating its robust test organization, initiated the Sensors Directorate, and accomplished pioneering work in managing integration of the Ballistic Missile Defense System.

Dr. Sanders has actively supported professional, academic, and civic organizations, serving on numerous executive boards. She is a Fellow of the American Institute of Aeronautics and Astronautics and has received three Presidential Rank Awards for executive achievements. She was awarded the Allen R. Matthews Award for significant accomplishments in test and evaluation and the AIAA DeFlorez Award for Modeling and Simulation, which recognizes achievements in its aerospace applications.

Mr. David B. West, CSP, ASP, PE, CHMM

- Examinations Director, Board of Certified Safety Professionals (BCSP)
- Former Vice President and Deputy Operation Manager, Science Applications International Corporation
- Chair, G-48 System Safety Committee of SAE International
- Former Vice Chair, Systems Management Council of SAE International
- Former Member and Treasurer, BCSP Board of Directors

Mr. David B. West is the Examinations Director at the Board of Certified Safety Professionals (BCSP). He is responsible for BCSP activities involving the development, validation, maintenance, and administration of examinations for BCSP certification candidates in the safety, health, and environment field. He previously served as an engineer and system safety subject matter expert for Science Applications International Corporation (SAIC) in positions of increasing responsibility, including vice president, deputy operation manager, and operation-level chief technology officer. In more than 28 years with SAIC, Mr. West's work helped ensure safety of a variety of systems and programs of national importance, including U.S. Army manned and unmanned fixed wing aircraft and helicopters, military ground vehicle immersive training systems, rocket launching weapon systems, precision targeting systems, chemical weapons destruction facilities, uranium enrichment and other nuclear operations, super-conducting magnetic energy storage technology, petroleum refining and chemical manufacturing, the Space Station Freedom Program, Space Shuttle microgravity experiments, and the Space

Shuttle range safety system. In more recent years, Mr. West learned and applied the concepts of software system safety on various projects.

For many years, Mr. West has actively led or supported standards-developing activities for system safety and other specialty engineering disciplines. Since 2010, Mr. West has chaired the G-48 System Safety Committee, currently under SAE International. He was one of the authors of the G-48 Committee's "Standard Best Practices for System Safety Program Development and Execution," GEIA-STD-0010, and was the sponsor of its first major revision. From 2017 through 2018, Mr. West served as the Vice Chair of SAE International's Systems Management Council. Mr. West served on the BCSP Board of Directors from 2008–2013 and was the Board's Treasurer from 2012–2013.

Mr. West is a Fellow Member of the International System Safety Society (ISSS) and was awarded its highest honor, the Professional Development Award, in 2013. He was also named the ISSS Manager of the Year in 2010. Mr. West was active in Toastmasters International from 2009 through 2017, and has been an invited speaker on system safety topics at several national and international events, including the 1st International Helicopter Safety Symposium in 2005, the FAA 9th Annual Commercial Space Transportation Conference in 2006, the Australian System Safety Conference in 2013, and numerous International System Safety Conferences since 2001.

Mr. West eared a B.S. in Nuclear Engineering from the University of Cincinnati. He holds the Certified Safety Professional (CSP), Associate Safety Professional (ASP), and Certified Hazardous Materials Manager (CHMM) credentials, and is a registered Professional Engineer (PE). Mr. West enjoys astronomy, triathlon, and traveling.

Richard S. Williams, MD, MPH, FACS

- Director, Three Rivers Health District, Virginia Department of Health
- Senior Aviation Medical Examiner, Federal Aviation Administration
- Former NASA Chief Health and Medical Officer

Dr. Richard S. Williams is a surgeon and aerospace medicine physician who currently serves as Director of the Three Rivers Health District. He leads 10 public health departments serving a 2,000 square mile rural area in Virginia's Middle Peninsula and Northern Neck, responsible for public health care and environmental health support to a population of about 140,000. He is also an active Federal Aviation Administration Senior Aviation Medical Examiner, performing aviation medical examinations and providing aeromedical consultation services for all classes of airmen. Previously, he served as NASA's Chief Health and Medical Officer. He spent 27 years in the United States Air Force as a general surgeon, flight surgeon, and medical manager and leader, domestically and in contingency operations abroad.

Dr. Williams reported to NASA Headquarters as an Air Force Colonel in 1998. He served as Director of the Office of Health Affairs and entered the Senior Executive Service as NASA's Chief

Health and Medical Officer in 2002. He led NASA's health care team through the construction and initial operation of the International Space Station and the final years of the Space Shuttle Program. His responsibilities included leadership, policy, oversight and advocacy for astronaut health care, NASA employee health care, protection of research subjects and bioethics. During his 15-year tenure, Dr. Williams led efforts to secure legislative authority for beyond-career astronaut health care, implemented Health and Medical Technical Authority, produced policies on ethics-based risk assessment for astronaut health and medical exposures during space flight missions, and fostered cooperative efforts between NASA's Human Research Program and health care system to better understand space flight related health risks and mitigations.

Dr. Williams received a B.S. degree from the College of William and Mary in 1975, an MD degree in 1979, and an MPH degree in 1996, both from Virginia Commonwealth University. He completed general surgery residency at Wright State University in 1984, and aerospace medicine/occupational health residency at the USAF School of Aerospace Medicine in 1998. He is a Fellow of the American College of Surgeons and maintains certification by the American Board of Preventive Medicine in Aerospace Medicine. His awards and decorations include the Bronze Star medal, the Meritorious Service Medal, the John R. Tamisea Memorial Award, NASA's Space Flight Awareness Award for Safety, the Melbourne C. Boynton Award, Senior Executive Service Presidential Rank Award, W. Randolph Lovelace Award, Forrest M. and Pamela Bird Award, the NASA Exceptional Leadership Medal and the NASA Distinguished Service Medal. He has contributed to and published numerous articles and book chapters in the medical literature.

Lieutenant General Susan J. Helms, USAF (Ret.)

- Independent Consultant and Principal of Orbital Visions, LLC
- Former Commander, 14th Air Force, Air Force Space Command
- Former Commander, Joint Functional Component Command for Space, U.S. Strategic Command
- Former NASA Astronaut

Lieutenant General Susan J. Helms, USAF (Ret.), is currently an independent consultant and the Principal of Orbital Visions, LLC. She is also on a number of Boards, including the Board of Trustees for The Aerospace Corporation.

General Helms has almost 36 years of military service in the U.S. Air Force. In her last assignment, she was Commander, 14th Air Force (Air Forces Strategic), Air Force Space Command; and Commander, Joint Functional Component Command for Space, U.S. Strategic Command, Vandenberg Air Force Base, CA. As the U.S. Air Force's operational space component, General Helms led more than 20,500 personnel responsible for providing missile warning, space superiority, space situational awareness, satellite operations, space launch, and range operations. As Commander, Joint

Functional Component Command for Space, she directed all assigned and attached space forces providing tailored, responsive, local, and global space effects in support of national and combatant commander objectives.

General Helms was commissioned from the U.S. Air Force Academy in 1980 and is a distinguished graduate of the USAF Test Pilot School (Flight Test Engineer Course). She has served as an F-15 and F-16 weapons separation engineer and as a flight test engineer for the CF-18. She has also commanded the 45th Space Wing, Patrick Air Force Base, Cape Canaveral, FL, and served as the J5, U.S. Strategic Command.

Selected by NASA in January 1990, General Helms became an astronaut in July 1991. On January 13, 1993, then an Air Force Major and a member of the Space Shuttle Endeavour crew, she became the first U.S. military woman in space. She flew on STS-54 (1993), STS-64 (1994), STS-78 (1996) and STS-101 (2000), and served aboard the International Space Station as a member of the Expedition-2 crew (2001). A veteran of five space flights, General Helms has logged 211 days in space, including a spacewalk of 8 hours and 56 minutes, a world record.

Captain Brent W. Jett, Jr., USN (Ret.)

- Independent Aerospace Industry Consultant
- Former Deputy Manager, NASA Commercial Crew Program
- Former Director, Flight Crew Operations, Johnson Space Center
- Former NASA Astronaut

As a member of the NASA Aerospace Safety Advisory Panel, Captain Brent W. Jett, Jr., is continuing a distinguished 37-year history of public service as a U.S. Navy fighter pilot, NASA astronaut, and member of the Federal Government Senior Executive Service. He also currently runs his own consulting company, Jett Consulting Services, with clients in the aviation and aerospace industry.

Captain Jett's career at NASA lasted from 1992 to 2013. His last assignment was as Deputy Manager for the NASA Commercial Crew Program, where he was charged with developing the new space systems to transport astronauts on missions to the International Space Station (ISS). In that role, he was instrumental in crafting the innovative acquisition strategy that will renew the American capability to launch humans into space. Prior to that assignment, Captain Jett served as the Director of Flight Crew Operations at the Johnson Space Center during the last three years of Space Shuttle operations. In that critical leadership position, he was responsible for planning, directing, and leading astronauts and aircraft operations in support of Space Shuttle and ISS missions. He was directly responsible for establishing the Gulfstream missions to fly returning ISS astronauts immediately to Houston, TX, after their Soyuz landing in Kazakhstan.

During his 26 years on active duty with the Navy, Captain Jett was a carrier fighter pilot (F-14 Tomcat), test pilot, and NASA astronaut. He flew four Space Shuttle missions (STS-72, 81, 97, and 115)—two as Shuttle Pilot and two as Shuttle Commander, which included a mission to the Russian Space Station Mir and two missions to the ISS. During his time as an astronaut, Captain Jett also served as the NASA Director of Operations at the Yuri Gagarin Training Center in Star City, Russia. He retired from the Navy in 2007 with more than 5,000 flight hours in over 30 different aircraft along with 493 carrier landings.

Captain Jett earned a B.S. in aerospace engineering from the U.S. Naval Academy in 1981, graduating first in his class, and an M.S. in aeronautical engineering from the U.S. Naval Postgraduate School in 1989. He is also a Distinguished Graduate of the U.S. Naval Test Pilot School and the Navy Fighter Weapons School (TOPGUN). During his military and NASA career, Captain Jett was awarded the Legion of Merit, Distinguished Flying Cross, Department of Defense Superior Service and Meritorious Service Medals, Navy Commendation Medal, NASA Exceptional Service Medal, NASA Exceptional Engineering Achievement Medal, NASA Outstanding Leadership Medal, four NASA Space Flight Medals, and various other service awards. He currently resides in Ponte Vedra, FL.

Dr. Donald P. McErlean

- Senior Aerospace Engineering Consultant
- Faculty member, Baylor University, Waco, Texas
- Former Engineering Fellow/Research Scientist, L-3 Technologies
- Former Director, Aerodynamics and Mechanical Engineering and Industrial Design, L-3 Technologies, Platform Integration Division
- Former Chief Engineer, Naval Aviation, Naval Air Systems Command

Dr. McErlean is currently a senior aerospace engineering consultant. A member of NASA's Aerospace Safety Advisory Panel, he specializes in airworthiness, certification, and airframe engineering and safety. He is also a member of the Faculty of Baylor University, College of Engineering and Computer Science.

From 2007 until 2016, Dr. McErlean was employed by L-3 Technologies, where he served as an Engineering Fellow and Research Scientist of the Platform Integration Division of the Aerospace Systems Group. He was responsible for the management of research and development, technical assessment of new business opportunities, and development of technical personnel and policy strategies in support of the division. He also held organizational assignments as Director of Aerodynamics and Director of Mechanical and Industrial Design.

Dr. McErlean left Federal service in 2005 following a career of more than 35 years. Upon retirement, he became President of the Center for Strategic Analysis, which provided high-level expertise to both industry and Government in areas of national interest, emerging technology, and public policy.

From 1966 to 1994, Dr. McErlean served in the U.S. Air Force Reserve, retiring at the rank of Lt. Colonel. From 1970 until 1987, he served in various technical and management positions with Air Force Systems Command (AFSC) both as an active duty Air Force officer and a civilian engineer. Leaving AFSC in 1987, he was appointed a member of the Federal Senior Executive Service (SES) and served as the Director of Air Vehicle and Crew Systems Technology at the Naval Air Development Center. In 1994, he served in a joint assignment when the Navy and Air Force jointly selected Dr. McErlean to serve as Technical Director for the Joint Strike Fighter Program. In 1996, he joined the engineering management team of the Naval Air Systems Command and served as Head of the Air Vehicle Engineering Department, Executive Director for Command-Wide Test and Evaluation, and Executive Director of the Naval Air Warfare Center Aircraft Division. He subsequently served as the Deputy Assistant Commander for Logistics and Fleet Support and oversaw the Naval Aviation buildup for operations in Iraq and Afghanistan. In his final position prior to retirement from Federal service, Dr. McErlean was appointed Deputy Assistant Commander for Research and Engineering (Naval Aviation's Chief Engineer).

Dr. McErlean is the recipient of several SES awards for exceptional performance as well as the Presidential Rank Award from Presidents George W. Bush and William J. Clinton. In 1987, he received the Exceptional Civilian Performance Medal from the Air Force. He is the recipient of the Navy Superior Civilian Performance Medal and the Navy Distinguished Civilian Performance Medal, the Navy's highest civilian award for performance.

Dr. McErlean received his Ph.D. in aerospace engineering (fluid dynamics major, applied mathematics minor) from Rutgers University and an M.S.M. from the Sloan School of Management at the Massachusetts Institute of Technology.

Dr. George C. Nield

- Independent Aerospace Industry Consultant
- Former Associate Administrator for Commercial Space Transportation, Federal Aviation Administration
- Former Manager of the Flight Integration Office at the NASA Johnson Space Center
- Flight Test Engineering Graduate of the USAF Test Pilot School

Dr. George C. Nield, currently an Independent Aerospace Industry Consultant, was formerly the Associate Administrator for Commercial Space Transportation at the Federal Aviation Administration (FAA). Under his leadership, the office had the mission to ensure public safety during commercial launch and reentry activities, as well as to encourage, facilitate, and promote commercial space transportation. Dr. Nield has over 35 years of aerospace experience with the Air Force, at NASA, and in private industry.

Prior to joining the FAA, Dr. Nield was a Senior Scientist for the Advanced Programs Group at Orbital Sciences Corporation, where he worked on the Space Transportation Architecture Study, the 2nd Generation Reusable Launch Vehicle Program, and the Orbital Space Plane. Previously, he served as Manager of the Flight Integration Office for the Space Shuttle Program at the NASA Johnson Space Center, and later worked on both the Shuttle/Mir Program and the International Space Station Program. While on active duty with the Air Force, he was an assistant professor and research director at the USAF Academy. As a flight test engineer for the Air Force Flight Test Center at Edwards Air Force Base, he supported the A-7 DIGITAC program, the YC-14 Advanced Medium STOL Transport, and the Space Shuttle Approach and Landing Tests. He also served as an astronautical engineer with the Space and Missile Systems Organization, identifying technology requirements for military space vehicles.

A graduate of the USAF Academy, he holds an M.S. and Ph.D. in Aeronautics and Astronautics from Stanford University and an MBA from George Washington University. He is also a flight test engineering graduate of the USAF Test Pilot School. Dr. Nield is a registered Professional Engineer and a Fellow of the American Institute of Aeronautics and Astronautics.

Captain Christopher Saindon, USN (Ret.)

- First Officer, JetBlue Airways
- Former Director of the U.S. Naval School of Aviation Safety and Flight Instructor at Training Squadron TEN
- Former Director of Aviation Safety Programs at the U.S. Naval Safety Center
- Former Navigator, USS Enterprise (CVN-65)
- Former Navigator, USS Harry S. Truman (CVN-75)
- Former Commanding Officer, Patrol Squadron FORTY

Captain Saindon is currently a First Officer with JetBlue Airways. He retired in February 2017 after more than 27 years of naval service. Immediately prior to retiring from active duty, Captain Saindon served as the Director of the U.S. Naval School of Aviation Safety at NAS Pensacola and a flight instructor at Training Squadron TEN from May 2015 to February 2017.

Captain Saindon hails from Orlando, FL, and attended the University of Central Florida, where he earned a B.S. in psychology and statistics in August 1989. Captain Saindon was selected to attend U.S. Navy Aviation Officer Candidate School at Naval Air Station Pensacola, FL, and was commissioned as an Ensign in April of 1990. He completed Navy flight training at NAS Whiting Field and NAS Corpus Christi, earning his Navy "Wings of Gold" in September 1991.

Captain Saindon's Navy operational flying assignments included numerous squadron tours flying the Lockheed P-3C Orion Maritime Patrol and Reconnaissance aircraft on missions around the globe. He attained every available qualification in the P-3C Orion, including Tactical Mission Commander, Instructor Pilot, Fleet Evaluation Pilot, and was a squadron Aviation Safety Officer. Captain Saindon served the Commanding Officer of Patrol Squadron FORTY from 2007 to 2009.

In addition to his aviation assignments, Captain Saindon served as Ship's Navigator aboard both the USS Enterprise (CVN-65) and USS Harry S. Truman (CVN-75) from 2009 to 2013 where he qualified as Command Duty Officer Underway and completed three separate work-up and training cycles, and a deployment to the Middle East and the Mediterranean.

Captain Saindon's other Navy assignments include Patrol Squadron THIRTY as a P-3 Fleet Replacement Squadron Instructor Pilot and Fleet Standardization Evaluator, Naval Personnel Command as the Aircraft Carrier Placement Officer; Naval War College, where he earned a master's degree in national security strategy and policy; and Naval Safety Center as Director, Aviation Safety Programs.

Captain Saindon qualified as a Federal Aviation Safety Officer and has logged more than 5,500 flight hours in numerous military and civilian aircraft.

Dr. Sandra H. Magnus

- Principal of AstroPlanetview, LLC
- Former Executive Director of the American Institute of Aeronautics and Astronautics (AIAA)
- Former Deputy Chief, NASA Astronaut Office, Johnson Space Center
- Former NASA Astronaut

Dr. Sandra H. "Sandy" Magnus, currently the Principal of AstroPlanetview, LLC, is the former Executive Director of the American Institute of Aeronautics and Astronautics (AIAA), the world's largest technical society dedicated to the global aerospace profession.

Born and raised in Belleville, Ill, Dr. Magnus attended the Missouri University of Science and Technology, graduating in 1986 with a degree in physics and in 1990 with a master's degree in electrical engineering. She received a Ph.D. from the School of Materials Science and Engineering at Georgia Tech in 1996.

Selected to the NASA Astronaut Corps in April 1996, Dr. Magnus flew in space on the STS-112 Shuttle mission in 2002, and on the final Shuttle flight, STS-135, in 2011. In addition, she flew to the International Space Station on STS-126 in November 2008, served as flight engineer and science officer on Expedition 18, and returned home on STS-119 after four and a half months on board. Following her assignment on Station, she served at NASA Headquarters in the Exploration Systems Mission Directorate. Her last duty at NASA, after STS-135, was as the deputy chief of the Astronaut Office.

While at NASA, Dr. Magnus worked extensively with the international community, including the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA), as well as with

Brazil on facility-type payloads. She also spent time in Russia developing and integrating operational products and procedures for the International Space Station.

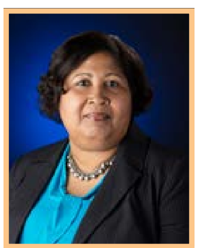
Before joining NASA, Dr. Magnus worked for McDonnell Douglas Aircraft Company from 1986 to 1991, as a stealth engineer. While at McDonnell Douglas, she worked on internal research and development and on the Navy's A-12 Attack Aircraft program, studying the effectiveness of radar signature reduction techniques.

Dr. Magnus has received numerous awards, including the NASA Space Flight Medal, the NASA Distinguished Service Medal, the NASA Exceptional Service Medal, and the 40 at 40 Award (given to former collegiate women athletes to recognize the impact of Title IX).

Aerospace Safety Advisory Panel Staff Members

Ms. Carol Hamilton, ASAP Executive Director

Ms. Carol Hamilton, Executive Director of the ASAP since 2015, has specialized in system safety engineering for more than 25 years. Her career also includes experience in systems engineering, systems verification, and system test engineering for both NASA space systems and the Department of Defense systems. During her time at Goddard Space Flight Center (GSFC) from 1991 to 2015, Ms. Hamilton contributed to more than 15 space flight missions, servings as a Senior System Safety Engineer for Hernandez Engineering for 8 crewed Space Shuttle missions and later as the Project Safety Manager for 14 uncrewed space missions. During her NASA career, she has been an instructor for the NASA Safety Training Center and has served on a number of NASA mishap investigation boards.



Ms. Evette Whatley, ASAP Administrative Officer

Ms. Evette Whatley joined NASA Headquarters in 2014, in the Office of International and Interagency Relations, supporting both the Aeronautics and Cross-Agency Support Division and the Advisory Committee Management Division. Before coming to work with the ASAP, she also worked in the Office of the Chief Technologist. Prior to NASA, Ms. Whatley was employed with the Department of the Navy and Department of Defense at various stations and commands in Norfolk, VA; Ceiba, Puerto Rico; Memphis, TN; and Lemoore, CA. She had her start in employment working as a substitute teacher and as an emergency replacement teacher in the Reef-Sunset Unified School District in Avenal and Kettleman City, CA. Ms. Whatley received her B.S. degree from Old Dominion University, Norfolk, VA.

Ms. Paula Burnett Frankel, ASAP Annual Report Editor

Ms. Paula Burnett Frankel has worked with the ASAP since 2009. She started her NASA career at the Goddard Space Flight Center, later transferring to NASA Headquarters where she served as program planning specialist in the Office of Space Science and Applications until 1989, when she left NASA for the private sector. Since 1994, Ms. Frankel has been a self-employed contractor—PB Frankel, LLC—providing documentation and editing services to various NASA organizations, the NASA Advisory Council and Committees, the 2002 Columbia Accident Investigation Board, the Return to Flight Task Group, and the 2004 President's Commission on Implementation of United States Space Exploration Policy. Ms. Frankel received her B.A. degree from Marshall University, Huntington, WV.





AEROSPACE SAFETY ADVISORY PANEL

Dr. Patricia A. Sanders, Chair
Lieutenant General Susan J. Helms, USAF (Ret.)
Captain Brent W. Jett, Jr., USN (Ret.)
Dr. Sandra H. Magnus
Dr. Donald P. McErlean
Dr. George C. Nield
Captain Christopher M. Saindon, USN (Ret.)
Mr. David B. West
Richard S. Williams, MD, FACS

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