AEROSPACE SAFETY ADVISORY PANEL

Annual Report *for* 2020

NASA AEROSPACE SAFETY ADVISORY PANEL

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

January 1, 2021

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 2020 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 2020 fact-finding; quarterly public meetings; direct observations of NASA operations and decision-making; discussions with NASA management, employees, and contractors; and the Panel members' past experiences.

There has been a significant amount of notable activity in 2020 in the Commercial Crew Program, ongoing operations of the International Space Station, and progress toward the execution of the Artemis missions, all undertaken in the shadow of the COVID-19 pandemic with which NASA has dealt commendably. The Panel will provide our brief assessment of those programs, but the ASAP has chosen to place greater emphasis in this year's report on NASA's future and its impact on the risks involved in human space exploration.

NASA has been at the forefront of human space flight for decades, and much of that time it executed the programs, formulated the missions, defined the requirements, and performed management integration of all the elements composing the system. NASA personnel performed the engineering analyses. They led launch processing and mission operations. But the human space flight environment is rapidly changing. The commercial space industry is growing briskly, bringing innovations and economic benefits. Global interest in space is increasing and, with it, the expectation for more international cooperative efforts. These developments have tremendous upside potential—and are accompanied by equally tremendous challenges for managing the risk of human space exploration.

Over the past several years NASA has been adjusting to a changing role and set of responsibilities as it shifts from principally executing its programs and missions to commercially acquiring significant key elements and services. The Agency has gradually and tactically adapted and succeeded in meeting emerging situations and challenges as they developed. However, the Panel firmly believes that it is now critical for NASA to take more strategic scrutiny of the role the Agency should undertake going forward and make some critical decisions, based on deliberate and thorough consideration, that are necessary because of their momentous consequences for the future of human space exploration, and in particular, for the management of the attendant risks. This report will provide the ASAP's advice to the Agency with respect to the questions that NASA should ask itself to strategically and thoughtfully position itself and the nation for success and safe human exploration of space. In 2021 the Panel seeks to further explore the consequences of the Agency's evolution, with a focus on the implications for safety and risk management.

The ASAP made two formal recommendations this year, both of which addressed the Designation of a Lead Federal Agency for Civil Space Traffic Management, and this report will reemphasize the criticality of this issue.

I submit the ASAP Annual Report for 2020 with respect and appreciation.

Sincerely,

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, 2021

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

Dear Mr. President:

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Patricia Sanders

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NASA AEROSPACE SAFETY ADVISORY PANEL

National Aeronautics and Space Administration

Washington, DC 20546

Dr. Patricia Sanders, Chair

January 1, 2021

The Honorable Nancy Pelosi
Speaker of the House of Representatives
Washington, DC 20510

Dear Madam Speaker:

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The ASAP Charter and Quarterly Meeting Minutes can be found at *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 2020 is included as Appendix B, along with the closure rationale for recommendations closed in 2020. 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

During 2020, the Aerospace Safety Advisory Panel (ASAP or Panel) conducted one quarterly meeting hosted by Kennedy Space Center and, in the shadow of COVID-19, three virtual quarterly meetings and a number of virtual insight and fact-finding meetings over the course of the year. The Panel wishes to acknowledge the extraordinary challenges associated with the COVID-19 pandemic and commends NASA's response, which is addressed later in this report. The report also includes brief summaries of the Panel's observations of the safety and risk aspects of ongoing human space flight programs.

In addition, and at the request of the NASA Administrator, the ASAP undertook an assessment of NASA's aircraft fleet safety in order to inform future decisions on the operation and sustainment of that fleet. The report resulting from that investigation is attached as Appendix D. The ASAP will follow up on the key recommendations contained in the report over the coming year.

Open formal recommendations are covered in Appendix A, and several will be addressed in later sections of this report, especially those recommendations pertaining to micrometeoroid and orbital debris (MMOD) and space traffic management. We also want to call particular attention to the longstanding and still unresolved recommendation concerning investigations for critical human space flight mishaps. We continue to be troubled that current Authorization language is inappropriate and inadequate for today's systems. The urgency of addressing this issue has only increased since first raised in 2015.

II. Executive Summary

While there has been a significant amount of notable activity in 2020 in the Commercial Crew Program, ongoing operations of the International Space Station, and progress toward the execution of the Artemis missions, the Panel has chosen to place greater emphasis in this year's report on NASA's future and its impact on the risks involved in human space exploration.

NASA has been at the forefront of human space flight for decades, and for much of that time it executed the programs, formulated the missions, defined the requirements, and performed management integration of all the elements composing the system. NASA personnel performed the engineering analyses, and they led launch processing and mission operations.

But the human space flight environment is rapidly changing. The commercial space industry is growing and bringing innovations and economic benefits. Global interest in space is increasing and, with it, the expectation for more international cooperative efforts. These developments have tremendous upside potential—and are accompanied by equally tremendous challenges for managing the risk of human space exploration.

NASA leadership in human space exploration is still preeminent, but the Agency's role is evolving with critical implications for how risk and safety will be managed. Over the past several years, NASA has been adjusting to a changing role and set of responsibilities as it shifts from principally executing its programs and missions to commercially acquiring significant key elements and services. The Agency has gradually and tactically adapted and succeeded in meeting emerging situations as they developed and meeting challenges as they arise. But the Panel firmly believes that it is critical at this time that NASA take more strategic scrutiny of the role the Agency should undertake going forward.

The ASAP does not presume to suggest what that evolving role should be. Rather, we believe that NASA must make some strategically critical decisions, based on deliberate and thorough consideration, that are necessary because of their momentous consequences for the future of human space exploration and, in particular, for the management of the attendant risks. These decisions involve:

- What role NASA intends to perform going forward and why.
- How the Agency will interact with both commercial and international partners.
- How the Agency will address shared risks.
- What management practices will be employed.
- How the expectations will be communicated to their partners and to their workforce.
- How effective Systems Engineering and Integration will be accomplished.
- What the NASA workforce of the future should look like and how it will be achieved.

This report provides the ASAP's advice to the Agency with respect to the questions that NASA should ask itself to strategically and thoughtfully position itself and the nation for success and safe human exploration of space. In 2021 the Panel seeks to further explore the consequences of the Agency's evolution, with a focus on the implications for safety and risk management.

III. NASA's Human Space Flight Evolution

Like technology, NASA's human space flight missions have evolved since the Agency's inception in 1958, from Project Mercury through Apollo and Skylab, to Shuttle and International Space Station (ISS), and then to today's efforts as architected by the Human Exploration and Operations Mission Directorate's Exploration Systems Development (ESD) and Advanced Exploration Systems (AES) divisions. In parallel, NASA's roles in managing its human space programs and conducting day-to-day business on the ground and in space have also evolved. Today, this evolution is influencing the Agency's approach to its current human exploration campaign, affecting not only how NASA manages individual programs, but also whether or not the Agency has the insight, oversight, and management processes to actively manage critical risks during both development and real-time operations for the complex and wide ranges of the ESD and AES programs. In addition to illustrating the concern in this report, the Panel seeks to further explore the ramifications of this evolution with NASA in 2021, with a focus on safety and risk management.

A. Historical Evolution in NASA's Roles

To understand the connection to safety and risk management, first consider the evolving roles NASA has played in its programs. For its first several decades, NASA had been the executing organization for its human space flight programs—Mercury, Gemini, Apollo, and Skylab. Specifically, NASA formulated the missions, defined the system requirements for ground and flight equipment, and managed formal acquisition of predominantly industry-developed and manufactured systems. NASA also provided Level II management, i.e., NASA performed management integration over all of the various elements that comprised the complement of ground systems, launch vehicles, and spacecraft as well as any other support functions that were required. In addition, NASA personnel did much of the engineering analyses and led launch processing and mission operations.

FIGURE 1. Shuttle

The Shuttle program (shown in **Figure 1**) began with these same management roles. As the program matured in the early 1990s, management responsibility for greater shares of the ongoing development testing and processing work was gradually shifted from NASA to the prime contractors, although experienced NASA civil servants remained engaged in senior leadership. In spite of these shifts, NASA personnel continued to perform in-line, technical work in support of almost all program functional areas. Beginning at its outset in the mid-1990s, NASA's ISS program (shown in **Figure 2**) followed the Shuttle program's trend in defining and sharing management roles with its prime contractors, and also added international, government-agency partners in NASA-led management processes.

FIGURE 2. ISS

To facilitate cost savings and to foster industry-initiated innovation, NASA intentionally shifted still more management roles to its contractors in the Commercial Cargo and Commercial Crew programs, beginning with Commercial Cargo in 2006 (see **Figure 3**). While NASA retained control of mission formulation, instead of levying a complex set of detailed design requirements for bidding companies to design against and for NASA personnel to then operate, the Agency primarily specified higher-level mission performance, safety, and key interface specifications that had to be realized in the provider's designs and concepts of operations. With this approach, NASA intentionally delegated all development, systems engineering and integration, launch processing, and mission operations to the contractor, essentially buying delivery of ISS cargo and astronauts to Low-Earth Orbit (LEO) as an

FIGURE 3. SpaceX Dragon during a Commercial Cargo mission

end-item service. The procurement process for these programs was also streamlined as a method of reducing costs and giving the contractor freedom to innovate in design, development, and business practices.

The ESD programs—specifically Orion, Space Launch System (SLS), and the first two Artemis missions—reflect "traditional" NASA roles similar to those utilized in its previous, pre-commercial programs, although as a notable departure from NASA's best practices, Level II management and integration across flight elements and ground support systems is led from NASA Headquarters. This decision moves away from the usual NASA Field Center leadership for highly complex programs and moves back toward the original Space Station Freedom program structure, which was abandoned in 1994 during its transition to the ISS program led from the Johnson Space Center.

As another level of management complexity, the AES development effort is being formulated to incorporate multiple different acquisition and management approaches, both "traditional" and "commercial crew-like." For example, one element of the AES, the Gateway (shown in **Figure 4**), is being developed with more "traditional" NASA roles, which include NASA acting as the integrator of major elements provided by industry and international partners. For other flight elements of the AES effort, NASA has adopted roles more closely resembling the Commercial Cargo and Commercial Crew programs, including limited top-down program direction and guidance and, in some cases, limited to no participation in development, launch, and space operations. This includes the Human Lander System (HLS) (see **Figure 5**), an obviously critical and tightly integrated mission element in NASA's campaign to initiate lunar exploration.

FIGURE 4. Gateway

FIGURE 5. HLS

The following table summarizes NASA's shifting human space flight program roles over time and from program to program since 1958. As NASA shifts roles to industry, the shading in each role becomes lighter; a noted trend from left to right across the various NASA programs is apparent. It is this continuing shift in NASA's management approach to its most far-reaching and highest-risk human space exploration programs and missions that prompts the Panel's attention.

NASA's Evolving Roles in Its Human Space Flight Programs

Role	Mercury-Skylab	Shuttle	ISS	Commercial Cargo and Crew	ESD	AES-a 1	AES-b 1
Mission formulation				2			2
Define system requirements				3		4	3
Government acquisition process			4	5		4, 5	5
Level II management integration, SE&I					6		
Development tests and facilities							
Launch processing leadership and direct, technical participation		7					
Mission operations leadership and direct, technical participation							8

LEGEND

- NASA-managed/-led
- Shared responsibility
- Wholly contractor-managed/-led
- Not yet determined

NOTES

1. Different approaches for some AES elements are still being developed.
2. NASA-defined mission objectives, contractor-defined mission formulation.
3. NASA-defined safety and interface requirements only.
4. International partners participate in NASA-led management processes.
5. Streamlined and/or "innovative" procurement.
6. Level II NASA management and integration provided by NASA Headquarters.
7. Some responsibility shifted to contractor after ~ first decade of operations.
8. Open to proposal.

More recently, in addition to NASA's evolving management roles, there has been increasing dialogue both from inside the Agency and from its numerous stakeholders regarding the primary purpose of the Agency's human space flight programs. After the initial success of the Commercial Cargo program and early in their Commercial Crew efforts, NASA strategy coalesced around a goal to foster the commercialization of LEO access. This goal was aimed at reducing NASA launch costs, as was the commercial acquisition strategy, and, more broadly, to stimulate an independent, commercial American launch industry. This effort has grown colloquially within NASA from "commercialize LEO access" to "commercialize LEO." Most recently, this has evolved further into a broader emphasis on applying the commercial cargo and crew procurement and management strategies in NASA's ongoing and future human space exploration programs. The National Space Council articulated this intentional evolution as a formal goal to "commercialize" NASA's human space exploration efforts in their July 23, 2020, report, *A New Era for Deep Space Exploration and Development*:

> In the past, the United States Government took the responsibility for all aspects of human space exploration and development—defining the missions, designing the architectures, setting technical specification, overseeing industry contracts, and directly conducting operations. The government will continue to have a central role for the foreseeable future, however, but in *partnership* with private industry. In the future, the government will take on more indirect roles, such as being a *patron of research and development, a first buyer or anchor tenant for space goods and services, and a regulator* as necessary for public safety or national security reasons and to fulfill international obligations. [emphasis added]

B. Strategic Ramifications and the Need for Deliberate Action

It is the growing emphasis in shifting NASA's role from principally *executing* its programs and missions to NASA *buying* significant key elements and services—including in its most far-reaching human space exploration programs and missions (i.e., development-stage programs for its complex lunar and Mars campaign)—that has the Panel's attention. Because NASA's ability to directly affect mission safety and success also necessarily evolves with its changing role from executor to buyer, the ASAP recommends the Agency take the following very deliberate and transparent steps to explicitly consider the risk/benefit trades to each "partnership," communicate expectations consistent with each partnership, and establish management practices that reflect and deliver on those expectations, as described below.

1. Explicitly consider the risk and benefit to each partnership.

The ASAP made similar observations in 2013 and 2014, which were then focused on the "simplistic view of the choices" whether to make, manage, or buy a capability, as summarized in the table below from the *Aerospace Safety Advisory Panel Annual Report for 2014*:

Make	Manage	Buy
Characterized by customized products, perhaps one customer with unique requirements, specs, and design. The customer owns the design.	Characterized by products for which there is a limited but still somewhat open market. Still a Statement of Work, specs, and significant involvement by the customer, but the design is constrained by existence of products in adjacent markets.	Characterized by a larger number of customers and suppliers with very little customization of the product. May be selected from a portfolio of what is available in the market. Mature. Often fixed price.
EXAMPLES: Mercury, Gemini, Apollo, Mars Curiosity	**EXAMPLES:** Launch vehicles, solid-propellant rocket motors	**EXAMPLES:** Commercial satellite launch services

Going into 2021, NASA remains challenged with the same decisions necessary to manage Artemis cost, schedule, and technical risk—namely, which space flight systems and services to make, manage, or buy. The answer is a moving target and will vary for individual flight elements and services as NASA and industry expand the combined experience base and as established industry providers build their own experience and offer market-driven services.

As NASA begins its extraordinarily complex lunar exploration campaign, the Artemis missions will employ a wide suite of new spacecraft and ancillary equipment to conduct operations that have not been performed since 1972. The success of the development efforts and the missions will directly affect both the safety of the astronauts onboard and the ability of the Agency to continue on to Mars. Successfully orchestrating parallel and complex developments and operational missions into an integrated system of systems—which include launch vehicles, crew capsules, landers, and orbiting modules—entails a vast array of interrelated decisions that share and manage risk across the full Artemis architecture. Further increasing the already high inherent risk is the combination of new development, schedule pressure, and the relatively low global experience base—across both industry and government agencies—pertaining to human operations beyond LEO.

The make-buy decision—or "partnering" approach—to transition an established operational environment with proven flight systems—e.g., LEO launch services and orbit operations—to a service provider incurs relatively describable and understood risks because of the broad and comprehensive foundational experience base resident within both NASA and broadly across industry. NASA choosing to utilize commercial airlines for business travel rather than relying on its own fleet of passenger aircraft serves as an example of risks leading to a decision to buy. However, it is a much different risk and value proposition to delegate development and/or operations literally at the frontier of NASA's human space exploration beyond LEO, where risks are much less bounded by experience and have previously been actively managed by NASA as an executing organization.

The Panel therefore recommends that NASA and its stakeholders formally assess the risks and goals in committing any human space flight element or program to a "partnered" or "commercial" management approach as a first step in determining a risk-managed strategy.

2. Transparently communicate expectations consistent with each partnership.

The commercial crew-like "partnering," as envisioned already for some AES programs, provides NASA with different avenues for cost savings and innovation than its "traditional" management approach. However, the "commercial" approach leaves NASA with little or no mechanisms to leverage the considerable experience and expertise resident in the Agency and its technical authorities to manage risk. This point was made during the May 5 and May 8, 2020, ASAP meetings regarding the Commercial Crew Program (CCP), Artemis, and the HLS:

> In considering the safety implications of NASA's relationship with suppliers/vendors/contractors, the Panel calls particular attention to understanding and defining the distinction between "we" and "they," both in communication and in execution. If the distinction is blurred, unintentional risks may be incurred. For example, NASA may unintentionally imply that the Agency is taking responsibility and/or action in solving an engineering problem or managing risk, when it is the contractor that remains responsible and should act.

> Clarifying the role that NASA intends for the long term is also important for strategic workforce planning. Without understanding that role, the Agency could erode experience and expertise in conducting launch and flight operations [in deference] to private companies that may or may not be available or able to conduct future exploration-related flight operations. Thoughtful attention to defining the key skills NASA needs to retain may prove important to the nation's overall space objectives in the future.

Regardless of the role NASA chooses in managing its exploration programs, the Panel recommends NASA program managers clearly and explicitly communicate the risk-benefit decision, rationale, and the resulting expectations for risk management and mission assurance, to all levels within NASA and to its stakeholders. This is a necessary step in order to unambiguously levy and define accountability internally commensurate with the chosen level of "partnering." It is similarly necessary to transparently inform external stakeholders of any shifted roles, responsibilities, and accountability from NASA to a "partner."

3. Establish deliberate management practices that reflect and deliver on those expectations.

Given the system development and mission complexity in the Artemis campaign, it is not clear to the Panel that NASA has deliberately studied and applied different management approaches that would be required to "buy" delivery of key AES flight elements and mission milestones—whether as "commercial crew-like" procurements of systems or as services. NASA insight and participation are deliberately and greatly reduced through the roles it assumes in its "commercial" approach, leaving it with limited to no ability to provide the Systems Engineering and Integration (SE&I) required to orchestrate the end-to-end effort. It is therefore not apparent that NASA has established management practices that will integrate different acquisition approaches in a holistic, risk-managed manner.

SE&I is critical in any development program. Certainly, in the past year, both the CCP and ESD programs experienced some difficulties with SE&I. This critical function will be as or more challenging for the AES programs and the Artemis missions as a result of the greater mission complexity and the procurement strategies. (This will be elaborated further in the next section of this report.)

The Panel therefore recommends that NASA ensure that its program management strategies and processes are implemented to reflect the chosen and transparently communicated "partnering" approach—as described above—and the resulting expectations for roles and real accountability.

In summary, if NASA, as the leader of the entire human exploration initiative, intends to evolve further into "buying" its highest-risk flight elements and mission services in human space flight exploration (i.e., AES flight elements and missions), rather than "executing" its more developmental programs, the Panel recommends that NASA and its stakeholders deliberately consider and answer the following questions:

- What deliberate management mechanisms will NASA employ from Headquarters down to the supporting organizations to assess which flight elements and/or mission services to "execute" versus "buy," and how will NASA deliberately manage the associated risks?
- How does this change expectations from within NASA and from its stakeholders in NASA's ability to manage development and operational risk?
- How will NASA change its risk management and acceptance approach, SE&I, and program management for critical flight elements and mission services with low/no experience base?
- Given that critical space flight experience is likely to migrate to proprietary contractual arrangements, how will NASA retain the experience and expertise to safely and effectively manage future complex and developmental human space flight programs (e.g., Mars missions) and their significant risks?

Many of the challenges described in the following sections of the report are directly influenced by this evolution in NASA's management roles in its programs. Again, the ASAP is deeply concerned that NASA's ability to directly affect mission safety and success also necessarily evolves with its changing role from executor to buyer. The Panel seeks to further explore the ramifications of this evolution with NASA in 2021, with a focus on safety and risk management.

IV. Systems Engineering and Integration

According to the *NASA Systems Engineering Handbook* (NASA/SP-2016-6105, Rev. 2):

> Systems Engineering is a holistic, integrative discipline, wherein the contributions of structural engineers, electrical engineers, mechanism designers, power engineers, human factors engineers, and many more disciplines are evaluated and balanced, one against another, to produce a coherent whole that is not dominated by the perspective of a single discipline (page 3).

Historically, NASA has embraced the concept of SE&I for high-risk space flight endeavors with exemplary standards and an incredibly passionate culture of technical excellence in its practices. The Agency has an expert, dedicated workforce; has executed an established, disciplined set of processes for integrated, *risk-managed* decision-making integral to highly complex developments; and remains informed by decades of human space flight experience. There can be no doubt that adherence to key attributes of SE&I have underpinned NASA's historical achievements.

Although not an all-inclusive list, the following attributes provide an exemplar of NASA's SE&I approaches that prove foundational to its evolutionary successes:

1. Understanding 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.
2. Clear traceability of performance-based technical requirements from the highest level of a programmatic enterprise to the lowest supporting project.
3. Technical decision-making processes that focus on active risk management; operational viability; and clear lines of authority, accountability, and responsibility.
4. Organization of critical SE&I functions within the control of the overall program hierarchy.
5. Clear and consistent risk management processes across the enterprise, to include integrated risks and hazards.
6. Reasonable test and development schedules, at the enterprise level, consistent with funding, performance requirements, and necessary technical work throughout the program hierarchy.
7. Unambiguous configuration management, ensuring that program teams retain appropriate control of technical design, performance, assumptions, and analysis.
8. Critical documentation that ensures consistent application of enterprise guidance, through the distribution of Systems Engineering Management Plans, Interface Control Documents, Test and Evaluation Master Plans, Integrated Milestone Schedules, and so on.
9. For outsourced SE&I functions, contractual vehicles that convey clear guidance on responsibilities, authorities, and accountability for the combined government/industry SE&I program functions.
10. Verification and validation testing to demonstrate that space hardware and software components at all program levels meet the intended technical and performance design requirements, to include the software/hardware interfaces.

Adherence to principles such as those listed above has enabled NASA to manage the risks of highly complex flight vehicles and to repeatedly execute challenging human space flight missions to LEO and beyond, at a level technically unequalled by any other nation. Disciplined SE&I processes, implemented by an incredibly talented workforce, has been the "secret sauce" that has made NASA's accomplishments the envy of the world. However, despite the admirable track record throughout its evolution, the Agency now has two significant SE&I challenges at the forefront:

1. **Commercial Crew Program (CCP):** The incorporation and sustainment of two major commercial "fee for service" delivery capabilities to continue human/cargo transport support for the ISS.
2. **Advanced Exploration Systems (AES):** The development, integration, and execution of a "Moon mission" to deploy and sustain both a lunar surface infrastructure for human presence and a human-tended station in lunar orbit.

Both of these initiatives (one of which is now in execution) will challenge NASA's SE&I capabilities in different ways.

A. SE&I Challenges of the CCP

As explained in Section III, NASA's Human Space Flight Evolution, the CCP management approach requires NASA to develop innovative tactics to retain appropriate technical, risk-managed oversight over commercial development programs that they do not directly control. One CCP provider, Boeing, has had a long-standing culture of SE&I that closely matches NASA's historical approaches. The other CCP provider, SpaceX, has a culture of "constant improvement," which embodies a philosophy of continual incremental design adjustments as hardware/software performance problems are identified.

The "spiral development" approach incorporating continual improvement has dramatically altered NASA's thinking about "certification" in the traditional sense and challenged traditional methodologies. An acquisition strategy that specifies the delivery of a service unleashes innovation and agility in the contractor community by minimizing interference from government to the overall benefit of both the government and the industry. A space flight program that allows for agility, innovation, cost control, and quick-turn technical improvements on a previously unimagined scale has definite advantages for NASA—as long as the necessary SE&I principles are sustained. Innovation and agility cannot be mutually exclusive to the application of critical SE&I principles that provide the cornerstone of effective risk management.

As NASA considers different acquisition mechanisms for future systems, an important aspect of SE&I is the need for contractual arrangements that clearly outline the "division of labor" and accountability for SE&I between NASA and the commercially contracted vendor. In a deliberative manner, NASA must determine what oversight arrangements are necessary to ensure that intended SE&I principles are appropriately implemented by the vendor. For example, despite the fact that the Agency contracted for a crew transportation service, NASA was compelled to deeply engage on the SE&I practices of both providers during the design and development phase of the program—in response to a variety of development challenges—to confirm that the processes, practices, and cultures of both providers were adhering to critical principles of SE&I.

To complicate matters, the initial contractual arrangements did not identify a NASA requirement for oversight of SE&I principles, which led to a "reactive" stance by NASA, as they only engaged after integrated designs were already codified, testing was already performed, and systems were already nearing completion by the providers. Without a clear understanding of how cogent system engineering and integration activities were being incorporated into the design and development of the systems, it was impossible for NASA to make timely, appropriate human space flight risk acceptance decisions. Consequently, NASA found itself in a reactive posture resulting in resource-intensive activity of "ad hoc" SE&I oversight late in the developments.

One notable example of a deficiency in suitable SE&I practices was a lack of clear understanding—across both the SpaceX and NASA engineering workforce—of system and operational margins of the Falcon 9 Composite Overwrapped Pressure Vessel (COPV) performance when integrated into the overall design. This lack of understanding led to a launchpad mishap of a non-NASA Falcon 9 mission. Another notable example was the validation and verification of the flight software for Boeing's Orbital Flight Test (OFT) vehicle. Due to some fundamental SE&I missteps, the OFT flight test not only did not meet the mission objectives, but it could have resulted in the loss of the vehicle. In summary, both of these examples highlighted a NASA risk management approach that was heavily reliant on NASA's well-established *risk assessment processes* of a completed vehicle design, but without requisite NASA understanding on SE&I *risk management* practices throughout the development phases. The object lesson from the CCP is that NASA should strategically think about how critical SE&I principles—which by necessity are incorporated throughout development—are assured in future commercial contracts.

The operational environment of LEO is one that NASA understands well, and NASA's ability to assess the risks of the CCP developments was advantaged by its deep, multi-decade experience. As human space flight expands beyond LEO and programs become more complex, it is important to document an appropriate distribution of SE&I roles, responsibilities, and authorities for both NASA and the service providers, with clear chains of accountability throughout developments. As noted in the previous description of NASA's evolution, the Artemis campaign, the next evolution of human space flight for the coming decades, encompasses a much more complex NASA/commercial SE&I integration challenge on a much more ambitious timeline and an advertised objective to again incorporate contracted commercial services for the HLS program. Consequently, the initial contractual arrangements will provide a rich opportunity for NASA to better incorporate the appropriate clarity for enterprise and program SE&I expectations and oversight.

B. SE&I Challenges for the Upcoming Artemis Campaign

NASA has determined that the next steps for human space flight lead to the Moon. As the Agency architects the mission, develops the requisite flight elements, and constructs the operational concepts, they are also charting the Agency's course for decades to come. The Panel has appreciated the many insights provided by NASA on how the Agency intends to develop and execute an incredibly complex campaign of interplanetary exploration, starting with the construction of a lunar infrastructure. However, the essential SE&I principles must remain as the cornerstone of critical integrated risk management in NASA's complex way forward.

Of special significance—counter to the well-known Apollo program of earlier decades—there is no such thing as a formally designated "Artemis program." Instead, there are lower-level, lunar-oriented programs such as Orion, SLS, Gateway, and HLS that will eventually integrate during lunar missions over the next several years. This lack of a top-level program designation, with an accountable program manager, has development and integration implications, and some SE&I challenges are already emerging. This will be an area of focus for the ASAP in the coming year.

1. Traceability of SE&I direction across the enterprise.

According to the *NASA Systems Engineering Handbook*, top-level guidance for the execution of complex programs is fostered by the establishment of a Systems Engineering Management Plan (SEMP), an Integration Plan, a Test and Evaluation Plan, and other key documents that provide the integrated technical management plan across the complex program enterprise. For example, the SEMP is a critical document that provides top-down direction for the roles and responsibility interfaces of the technical efforts and how those interfaces will be managed. The SEMP documents and communicates the technical approach; the resources to be used; and the key technical tasks, activities, and events, along with their metrics and success criteria. The Integration Plan describes the coordinated integration effort required to support the overall implementation strategy, including a description of what various sub-programs are required to do for each integration step. The Test and Evaluation Plan describes or specifies the type and amount of testing that needs to be done to validate the design and to assure that performance meets specifications. Other guidance, such as Interface Requirements Documents, is necessary to assure that the various programs within the enterprise can integrate with each other and operate as a whole to meet objectives.

The complexity of the Artemis campaign, which includes flight elements that are programmatically distinct, staggered in acquisition, and variable in their contractual arrangements, presents challenges in establishing top-level requirements guidance across the enterprise, especially given that there is no formal Artemis program, and therefore no SE&I direction, responsibility, and accountability at the Artemis campaign level. Consequently, as currently constructed, existing SE&I processes may apply only within a major program (e.g., SLS, Orion), and each major program views SE&I through its own particular lens.

The major program managers are following established NASA guidance for the management of their programs, but the current NASA guidance may not be adequate to address the complex SE&I challenges for a multi-mission exploration campaign that has not been formally designated as an official program. An additional challenge of the Artemis campaign is that many critical SE&I documents are delivered on individual program milestones, yet the many programs within the Artemis enterprise are in different development phases across many different contract teams, resulting in asynchronous schedules and delivery dates for similar products. The end result is that important SE&I documents have yet to be drafted within some programs, and given this staggered dynamic, it is currently unclear to the ASAP how the various program-level SE&I organizations work together to appropriately address enterprise-level SE&I principles that underpin safety and mission assurance.

2. Leadership and organization of the SE&I.

Due to the sheer complexity of the Artemis campaign, it is essential that SE&I organizational structure and functions are designed appropriately to assure the essential principles of SE&I, as listed above, are propagated across the totality of the Artemis enterprise. For example, NASA's objective is to return to the Moon and establish both a *lunar surface infrastructure* and a *lunar orbiting infrastructure* foundational to future efforts to reach Mars. This desired lunar infrastructure, intended to deploy over many years and many missions, requires the integration of several major current and future NASA programs—to include SLS, Exploration Ground Systems (EGS), Orion, Gateway, propulsion modules, spacesuits, and human lander systems—all executing on different development cycles. Some critical activities and projects are directly under NASA's internal program control (e.g., SLS software); some are in the traditional flavor of classic contractor development under NASA's oversight (e.g., Orion); some are provided by international contributors; and some are designated as "commercial" service contracts (e.g., HLS). Impacts of schedule and budget modifications for any particular program, no matter how it is contractually arranged, can and will have a rippling effect on the systems engineering of other contributing and integrated programs, as sub-program technical work gets rescheduled, rescoped, and rebalanced.

To assure that technical requirements and risk management standards remain consistent across this incredibly high level of complexity, a strong and comprehensive SE&I function with program authority and influence should exist at the campaign level and should execute under the direction of a campaign-level program manager. Every program manager under the campaign hierarchy must ensure that their developed capability—tied to consistent technical/safety decision processes—appropriately integrates with the broad enterprise and integrated technical baseline, such that the broadly defined Concepts of Operations (CONOPS), technical performance, testing programs, and interoperability remain sustainable, executable within program constraints, and risk-managed.

The leadership SE&I challenge facing NASA is how to establish a strategically coherent, well-understood, fully integrated SE&I organization with effective authority and accountability across the complexity of the Artemis enterprise, given that no formal Artemis program exists. This is considerably challenging as every distinct program has its own SE&I function, and nearly every program is at a different phase of development—let alone the considerable variation in how SE&I responsibilities are divided between NASA and its contractor workforce. The ASAP is concerned that a clearly articulated, comprehensive SE&I strategy that addresses the whole of the Artemis campaign with appropriate program authorities has not yet been baselined.

As currently defined, NASA has designated two program managers: one responsible for the ESD program and the first two ESD missions, and one responsible for the AES program and all follow-on missions. Neither of these program managers has issued direction detailing the coherent SE&I plan for the multiple programs that collectively make up the Artemis campaign. The ESD program, by far the most mature component of the Artemis-related architecture, does have an SE&I function, but the Panel has noted significant SE&I weaknesses, including a complex distribution of responsibilities and a lack of technical accountability for the integrated ESD system (source: NESC-RP-20-01519, Finding 5). It would behoove the ESD and AES leadership to quickly correct the existing SE&I organizational confusion and set an example to which other program managers can adapt and align.

In addition, as currently constructed, NASA has established a designated SE&I functional manager who is a direct report to Human Exploration and Operations leadership and is outside of the authorities of both Artemis program managers. As a result, it remains unclear to the Panel who actually holds key accountability for integrated SE&I across the whole enterprise and between component programs. Per NASA's own advertised practices, the actual "executors" of integrated SE&I should reside within the program management hierarchy. Therefore, the existence of a separate organization for "SE&I" appears counter to foundational principles regarding risk management and safety.

At every level of the Artemis development and operational hierarchy, SE&I functions should be organized to ensure a consistent influence within programs and projects, to demonstrate a coherent approach to SE&I principles, and to assure horizontal and vertical integration. Even across a wide array of contracts that direct variations in accountability for requisite SE&I functions, the traceability of roles, responsibilities, and accountability across the myriad of organizations should not be opaque.

3. Coherent technical/risk management decision processes.

As each individual flight element program develops and executes, it appears that clear accountability for integrated SE&I *risk management* decision-making (as opposed to *risk assessment*) is ambiguous. For example, the myriad of program/project decisions in technical management, verification and validation, test acceptance, and operational risk—that underpin a well-thought-out integrated SE&I plan that manages risk across both the ESD and AES programs—are not fully transparent. The Panel is very concerned that the current risk management decision-making process does not provide a mechanism for the technical decision authorities across different programs to clearly understand the implications of how one program decision may affect other programs as development proceeds. NASA should carefully consider and cultivate risk management decision processes that encompass the implications on all exploration programs and are capable of spanning the gaps caused by differing development schedules and variable acquisition approaches.

Another SE&I dynamic that will challenge the risk management and acceptance decision processes of the Artemis campaign is the lack of a regular flight rate cadence for exploration. In contrast, throughout the Shuttle and ISS programs, a typical flight rate of four or more flights per year required a regularly recurring, NASA-led process to review all technical and safety issues and overall flight readiness across the full enterprise (Certification of Flight Readiness [CoFR], Flight Readiness Review [FRR], and Stage Operations Readiness Review [SORR]). This included exercises by lower-level teams to assess and document readiness and open work for each flight element and team, the results of which were then integrated at the program and Agency levels for formal risk acceptance and a deliberate commitment to readiness. Through these reviews, NASA managers at all levels gave formal assurance that all hardware, software, and operations preparations had been delivered per specifications and program requirements and that all anomalous events in previous missions and during launch processing had been resolved. In parallel to the standard program management practices, conducting these reviews multiple times per year further enhanced awareness and deliberate risk management across all flight elements and at all management levels. As a prominent component of NASA's ongoing SE&I efforts, these recurring reviews also reinforced SE&I-related skills, communications, and management practices. In contrast, the ESD and AES programs are both projected to have a comparatively low flight rate, with SLS and HLS projected to fly less than once per year, diluting this systemic forcing function for a continual, program- and workforce-wide knowledge of the SE&I posture for the programs.

V. Workforce

This year, as in previous years, the Panel has commented on many issues related to the NASA workforce and the potential effects of these issues on safety and mission assurance. The evolution of NASA—its missions, management roles, and acquisition strategies—was discussed in Section III of this Annual Report. Of interest to the Panel is what effect this evolution is likely having and will continue to have on NASA's workforce and to what NASA should pay particular attention as it continues to evolve. In the following discussion, some additional workforce-related challenges and considerations are addressed.

A. Communication of Roles and Responsibilities

As noted throughout this report, NASA's changing program management roles and responsibilities are challenged by their increasingly ambitious and complex space exploration missions, including innovative strategies to acquire human space flight vehicles and services. In previous eras of NASA's evolution, the combined NASA workforce (civil service and support contractors) "owned" risk management in totality, and the combined workforce executed the entire Apollo program, built and flew decades of Shuttle/ISS missions, and developed Orion and SLS hardware and software. However, for commercially procured spacecraft and services, the skills necessary for the NASA workforce to execute risk management are likely to center on commercial contract oversight and will be highly dependent on how risk management roles and responsibilities are delineated in contractual arrangements. In assuming somewhat different management and technical roles, the specific expectations levied on individuals and teams at each NASA Center must also adjust. It may well be that the roles and responsibilities of a NASA workforce that executes enterprise risk management for commercially procured services requires skills and experiences that are substantively different than those of the current NASA workforce.

In the first half of 2020, the Panel raised specific concerns about the nature of the evolving relationship between NASA and the CCP contractors, calling particular attention to understanding and defining the distinction between "we" and "they"—in essence, the distinction between "customer" and "provider"—both in communication and in execution. As discussed in more detail elsewhere in this report, if the distinction between the differing roles is unclear, overlapping, or "blurred," unintentional risks may be incurred. For example, NASA may unintentionally imply that the Agency is taking responsibility and/or action in solving an engineering problem or managing risk, when it is the contractor that remains responsible and accountable. Given that different pockets of the workforce will have differing technical roles, depending on the nature of any given development program for the Artemis campaign, responsibilities and technical authorities must be communicated with complete clarity and codified in contractual vehicles, to ensure there is no confusion, particularly among those who are responsible for risk management throughout development.

B. Sustaining NASA's Technical Expertise

As NASA continues to explore "buying" spacecraft, launch vehicles, and services rather than performing as an executing organization for critical lunar landing capabilities, the questions posed at the end of Section III bear directly on the future of the NASA workforce. The considerable experience and expertise in the engineering and technical support teams at all NASA Centers are national assets that make NASA the "gold standard" technical agency of the world, but the very definition of "commercial procurement" is likely to dilute the technical role that NASA will play in near-term and longer-term human exploration. The deep expertise that resides within NASA may not necessarily be fully leveraged for developing, testing, and fielding "commercial" procurements that are delivering a service. To sustain a knowledgeable, experienced workforce, it would be critical for NASA leadership to ensure that NASA's technical experts—across all Centers—remain vibrantly engaged in the challenging risk management problems of human exploration. It will take careful consideration, if appropriate, to reallocate the existing technical workforce into areas of the NASA portfolio where the organization has retained the decision to execute development, systems engineering, and integrated risk management at all necessary levels.

There are certainly clear advantages of having commercial partnerships with an innovative industry, but NASA must ensure that the Agency retains its long-term "best of breed" technical edge, even as exploration development work is outsourced. The upcoming Artemis campaign will encompass an entire spectrum of options for the division of technical labor, from in-house work to fully outsourcing of "services," all depending upon the acquisition strategies of any given Artemis program. NASA has placed some of the most challenging exploration problems of the moment—e.g., the development of human lander systems—on the shoulders of "service providers," to critically design, analyze, integrate, test, and operate, all as a provision of "services" to NASA. In light of this reality, NASA should consider a comprehensive workforce strategy focused on a number of key parameters, including the retention and application of valuable technical talent to the hardest problems, as well as the continuing growth and development of an in-house workforce, capable of fully executing interplanetary exploration missions for the foreseeable future. In essence, execution of previous NASA in-house campaigns led the NASA workforce, over the years, to the standards of technical expertise and experience that they enjoy today. NASA leaders should be cognizant of how to strategically counterbalance the atrophying effect of "outsourcing" on the workforce.

In summary, it is not clear to the Panel that NASA is deliberately addressing certain workforce issues at the strategic level. Failing to do so could result in blurred responsibilities and the directly related concern that some risks may not be actively or adequately managed. It could also result in erosion of expertise and experience in the NASA workforce, thereby undermining NASA's ability to effectively manage the highly complex risk problems of future exploration programs, including those envisioned for the Artemis campaign.

VI. Risks from Inconsistent Goals, Unrealistic Schedules, and Resource Uncertainties

NASA is a "can-do" organization with a history of "making the impossible possible"; the Agency's technical accomplishments are amazing. This year, even in the face of adverse weather (multiple hurricanes) and the environment of the COVID-19 pandemic, the leadership and workforce have managed to safely sustain their critical operations and to continue development of their future human space flight programs. But passion for the mission, professional determination, and creative talent are not necessarily enough to address ever-present uncertainty and external pressures. The following three interrelated factors have the potential to lead to decisions that will undermine and erode the safe and successful execution of NASA's complex and challenging human space exploration mission:

- Lack of "constancy of purpose" for the U.S. space program.
- Technical baselines and schedules that are not mutually consistent, realistic, and achievable.
- Absence of adequate and stable resources.

When these factors exist, they present an even greater challenge for NASA to aggressively and decisively adapt the Agency to evolving roles, clarify responsibilities and authorities, lead from the front on campaign integration, and develop contractual arrangements that leverage the best of both NASA and the private industry in a holistic sense.

A. Constancy of Purpose

As the Panel has emphasized numerous times, space exploration is a far-reaching and long-term endeavor, and as such, requires a total and enduring national commitment, consistent over time and across Administrations. Sustained constancy of purpose and clear understanding of objectives are critical, not only to bringing to fruition investments made in ongoing programs, but also to capitalizing on the knowledge and understanding of their designs gained through development and testing. In addition, constant interruptions throughout the development process increase the risk to mission success due to disruptions in knowledge flow and retention. Although it is clearly appropriate for the U.S. Administration and Congress to direct NASA though guidance, policy, law, and appropriations, frequent and fundamental "re-directions" to NASA due to changes in national guidance and allocated resources drive the technical and management teams to continually reformulate exploration efforts, to the detriment of technical baseline stability, workforce focus, risk posture management and cost efficiencies, and—most importantly—safety. The ASAP continues to strongly caution that a lack of consistent commitment to the overall exploration mission at the national level negatively impacts NASA's inherent ability to execute an exploration campaign with full coherence of effort and cost-effective development.

Without a steadfastness in pursuing a long-term, consistent set of articulated goals, not only are cost, performance, schedule, and safety matters impacted, but also workforce morale and relationships with external partners. Instability in vision and direction can destroy credibility with industrial and international partners, Congress, and the public. This, in turn, can undermine support, which feeds into a detrimental cycle of program disruption that then further is perceived as, and magnifies, the lack of constancy of purpose, resulting eventually in the ultimate cancellation of programs and the failure to achieve mission and goals. This cycle has, unfortunately, been all too present in NASA's history, as noted by the cancellation of the Constellation program, the cancellation of the Asteroid Redirect mission, and the vacillation between exploration of Mars with and without precursor risk-reduction missions to the lunar surface.

B. Realistic Schedules

The declaration in 2019 that NASA astronauts will return to the Moon in five short years has added a vibrant urgency to an already complex and ambitious endeavor. An aggressive, yet realistic schedule, underpinned by a coherent technical baseline with clear, traceable objectives from the top leaders of NASA to the lowest projects, can provide impetus and inspiration for a highly talented workforce, leading to greater decision velocity, restructured and more efficient workflow, and innovative business practices. However, as NASA prepares to meet the exciting, but clearly aggressive goal of sending humans back to the Moon, it is critically important to develop realistic schedules. Unrealistic schedules can result in compromised decision-making—particularly from a safety perspective—if meeting these deadlines results in imprudent shortcuts or elimination of important testing. In addition, it can be detrimental to employee morale if the official dates are clearly not achievable when compared to the highly complex technical baseline. In these circumstances, workers critical to the risk management of the enterprise often perceive a culture of "schedule pressure"—the perception that schedules have a priority over other program attributes, including safety and mission assurance—whether that perception is intended or not. Acknowledging the value of setting challenging, but realistic and achievable schedules, NASA must guard against the perception of schedule pressure to the degree that the workforce will assume their own risk management concerns will be discounted or trivialized.

As NASA prepares to meet this aggressive yet exciting goal, while simultaneously continuing the CCP and ISS operations, the Panel continues to advise caution and diligence. We warn that targeted, advertised launch dates—while useful to impart a sense of urgency and a motivator for impressive accomplishment—should be used judiciously.

It is important for NASA to recognize that a dynamically complex, highly integrated number of critical data sets across all flight elements are required to quantify the risk, to understand operating margins, and to ensure the optimal safety of human flight. For example, documented data on the margins resulting from structural, thermal, acoustical, and propulsion testing, as well as integrated performance of critical systems such as the heat shield, parachutes, abort mechanisms, and Environmental Control and Life Support System, must be available and well understood across the entire mission profile before launching a new vehicle into space with humans on board. There are no shortcuts to achieving the requisite design understanding, although there may be many innovative ways to attain it.

Currently, NASA has been given a mandate (not yet fully supported by Congress) to meet a "Boots on the Moon" arrival date. This mandate is not fully funded, nor is the technical baseline of the campaign fully developed. Some aspects of the campaign (e.g., ESD) are in final phases of development, while other necessary flight elements (e.g., the HLS) are still just "on paper," without a fully defined technical baseline. While the desire to get Boots on the Moon as soon as possible is an understandable challenge goal, particularly in light of NASA's Apollo successes, NASA is attempting to build a long-term exploration program and a sustainable lunar infrastructure. Putting full consideration on the strategic trade space from a technical and development standpoint is the cornerstone of a holistic exploration program with a coherent schedule. Choices of how to schedule technical baseline content in the near term will have long-term implications on overall mission assurance and safety.

The challenge is that some flight elements necessary for the "Boots on the Moon in 2024" directive are, at this point, relatively immature concepts. In addition, there is no top-level set of integrated performance requirements across flight elements, no integrated test and verification plan, no campaign-level systems engineering management plan that would provide guidance on integrated schedule milestones. To lay out a realistic schedule for all of the necessary technical development/test/verification work content that would integrate the various flight elements together as a holistic set of synergistic, executable missions, the Agency would need to have a coherent enterprise-wide technical baseline that does not yet exist. At this time, it appears that NASA is making schedule decisions based only on the application of requirements necessary to achieve the first two flights; as yet, the broader risk assessments of the entire campaign for a lunar infrastructure, including Boots on the Moon, remain unaddressed—primarily because there is little to assess for a technical milestone schedule.

NASA and their program managers must make risk and safety important factors on informed decisions to balance cost, performance, and schedule, yet the NASA workforce continues to work toward a schedule that assumes that Boots on the Moon will be a reality by 2024. As the workforce strives to maintain a schedule that is, at best, single-flight focused, the implications for integrated safety risks across the campaign are disturbing. The NASA "can-do" attitude, while commendable, can be an unintended contributor that compromises risk assessments. Given a targeted milestone completion date, a program manager will diligently work to meet that date and balance schedule, budget, and approach to achieving performance—risk assessments within his/her own program included. It is vital to send the message to program managers—and to the workforce—that schedule is not an absolute constraint. Rather, it is an element of the trade space in their decision-making process, which includes considerations of safety and risk posture. Important technical and risk mitigation decisions that are driven by an unrealistic launch date without a clearly articulated set of safety principles that guide those decisions will compromise safety.

C. Resource Stability

A steadfast national commitment to pursuing clearly articulated human space exploration goals must be accompanied by a willingness to support those goals with the necessary resources. Budget inadequacies and instability—including the instability introduced by partial and full-year Continuing Resolutions (CRs)—add complexity and uncertainty to the highly complex program management across the entire NASA enterprise. The likely result is ongoing confusion around campaign and mission objectives, lack of clarity in development goals, mixed messages to the workforce about priorities, considerable resource inefficiencies, and ensuing questions about roles, responsibilities, and authorities—all detracting from the ability to prosecute the exploration campaign with the requisite focus on safety and mission assurance.

The triad of program management—cost, schedule, and performance—remains fundamental for successful program execution, and shortcutting any of the three increases overall program risk. If NASA is to achieve the expected performance, including mission assurance and safety, and reach the desired goals within reasonable timelines, the requisite resources must be made available. These funds must be provided with the necessary stability in order to plan and manage a feasible program of work. The history of resource ambiguity, resulting from year after year of CRs, adds complexity to program management and inefficiency to execution while creating a potential distraction from safety and mission assurance.

The budgetary practice of passing CRs in lieu of enacting true appropriations creates predictable problems for all government agencies, but for NASA, the unintended consequences of CRs can encompass increased risks to human life within an already challenging Agency mandate. Of critical concern to the ASAP is that the uncertainty about budgets ultimately can threaten safety and risk mitigation strategies as programs seek to make progress with ill-suited and inadequate funding profiles. For example, the CR in effect at the time of this writing challenges many aspects of NASA's program of work and significantly adds to the risk posture of the Artemis mission. Combining the uncertainty of the budget with the immaturity of the technical baseline and schedule pressure compromises the development of necessary technologies for deep space exploration and stresses testing, risk reduction, and safety activities under the AES program. In short, the already incredibly complex set of executable objectives becomes even more complex, and the implications for integrated risk management are momentous.

To summarize, regardless of how NASA addresses the technical challenges, the nation must avoid fluctuating policy goals, ambiguous objectives, budget inadequacies, and instability—including partial and full-year CRs—which add complexity and uncertainty to program management. Failing to do so seriously imperils the achievement of human exploration goals and the safe development of the complex systems on which those goals depend.

VII. Program Assessments

A. Exploration Systems Development


FIGURE 6. Installation of the adapter for mating the Orion spacecraft to the SLS rocket

Through the challenges of 2020, the Panel closely monitored the progress being made on ESD programs. Although COVID-19 and five hurricanes have complicated ESD program work, mission processing has continued, with some greater schedule risk to Artemis-II. Thermal vacuum testing of the Artemis-II Orion and Service Module assembly was completed at the Plum Brook Station in 2020, and the assembly was returned to the Kennedy Space Center, where it is undergoing final hardware operations prior to integration with the SLS rocket (see Figure 6). The Green Run tests have been interrupted and delayed by the aforementioned hurricanes, but they were anticipated to have been completed before the printing of this report. After successful completion of all Green Run tests on the SLS, including the full-duration hot fire test, booster stacking will begin at the Kennedy Space Center.

Several ESD issues have been the focus of the Panel's attention leading into, and continuing through, 2020. In previous years. the Panel had voiced concerns about certain aspects of the European Service Module's (ESM's) propulsion system. The original design approach had been to transition, after the first three Artemis flights, from a zero-fault tolerant, serial-valve configuration to a parallel configuration that included valve redundancy. A program decision was made to reconsider that approach in favor of enhancing the individual valves' designs toward greater reliability. While this plan had been presented to the Panel, an update with details on the success of its implementation is still awaited.

Another issue the Panel had a chance to review in 2020 was that of the Artemis program's abort capabilities. Five different abort modes have been assessed: use of the Launch Abort System, the Untargeted Abort Splashdown, Retrograde Targeted Abort Landing (not currently baselined for Orion missions), Abort Once Around and Abort to Orbit, and Early Interim Cryogenic Propulsion Stage (ICPS) Separation. Aborts can be triggered from five different sources: the SLS rocket, the Orion capsule, the ICPS, a Range Safety Flight Termination System command, or a manual command—either by the crew or from the ground. Under the current plan, Range Safety Flight Termination commands, if needed, would be sent manually for the first two missions, with an autonomous capability being implemented after that. Although such a capability does have cost implications, the Panel encourages

NASA to continue to look at how to incorporate an autonomous system, when feasible, since a fully qualified, tested, and certified autonomous system would eliminate the risk of human error causing inadvertent actuation, or failure to actuate when needed.

Through in-depth discussions in 2020, the Panel learned more about the hazard analysis process, which deals with hazards specific to each of the ESD programs, as well as cross-program integrated hazards. A well-defined Integrated Risk Working Group is responsible for processing the risks that may be identified through a number of sources, including the various program control boards. Active risk management can lead to new hazards, or modifications to hazards, in the hazard analysis process.

With respect to the understanding being gained of ESD safety risks and measures identified for reducing risk, the Panel has been pleased with the evolution and refining of Artemis-I, -II, and -III mission configurations, and specifically with the addition of proximity operations to the Artemis-II mission, for the purpose of reducing risk.

A significant concern identified this year, in the aftermath of the Boeing Starliner OFT anomaly, which involved unexpected behavior of software and communication systems, is the fact that there is no single test facility that can perform end-to-end, integrated avionics and software integration and testing. Instead, multiple and separate labs, emulators, and simulations are being used to test subsets of the software. In the coming year, the Panel will be closely following the efforts by NASA and the AES program office to address concerns over end-to-end integrated software test capabilities. The Boeing OFT anomaly highlighted the potential for similar escapes to pose significant risks to other programs, including AES programs and flight elements. This awareness has also pointed out the critical need for a rigorous and structured program of identifying and tracking lessons learned and their applicability to all NASA programs.

In early November, a failure was detected in one of two redundant sides of a power and data unit in the Orion crew module adapter. Access to the failed component for repair or replacement would have presented significant challenges. As this report was being finalized for publication, failure review boards and control boards met to decide the best course of action, between either using "as is" with the high degree of available redundancy, or incurring a several-months-long schedule delay to remove and replace the box. Engineers determined that due to the limited accessibility to this particular box, the degree of intrusiveness to the overall spacecraft systems, and other factors, the risk of collateral damage outweighed the risk associated with the loss of one leg of redundancy in a highly redundant system. Therefore, the decision was made to proceed with vehicle processing. As of this report date, NASA remains on track for the launch of Artemis-I in November 2021.

B. Advanced Exploration Systems

NASA has determined that the next steps for human space flight lead to the Moon. As the Agency architects the mission, builds the systems, and constructs the operational philosophy, it is also charting the course for the coming decades. The organizational, structural, cultural, and technical approaches that are adapted to execute an ambitious and comprehensive departure from our near environs in

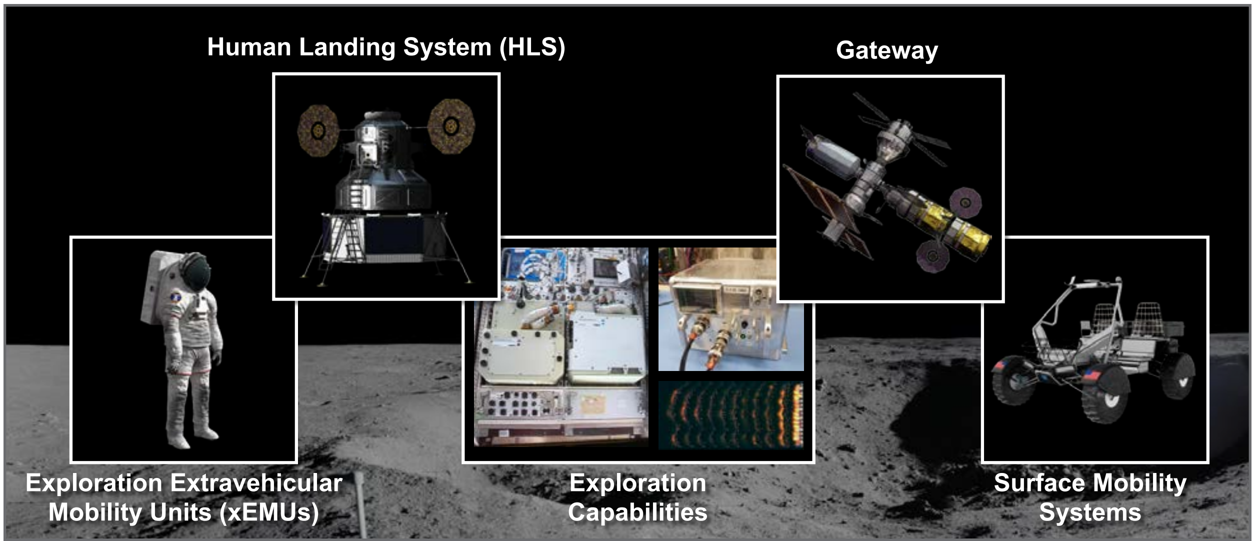

FIGURE 7. NASA's AES program comprises the additional elements needed for human operations in cis-lunar space and on the lunar surface

LEO will establish a precedent and build momentum for how NASA continues to execute going forward. Consequently, it is critical that the Agency think carefully about the approach they embrace and ensure that, to the maximum extent possible, lessons learned from past and current programs are carefully considered and incorporated into future plans. The ASAP would like to offer the following observations and suggestions, focused on safety and risk mitigation, for consideration as the approach for the AES program, as currently defined by NASA and illustrated in **Figure 7**, takes shape.

1. Acquisition strategy and budget.

The acquisition strategy being pursued for a human lander involves a competitively driven commercial services contract with an eventual down-select process to a final system or systems. This same approach will likely be used for other elements of the lunar infrastructure. The strategy includes a baselined amount of funding to support the contracting approach for system delivery in the 2024 timeframe. Unfortunately, like many NASA initiatives, the Artemis campaign has, from its very initial stages, been challenged by projected long-term funding shortfalls. How the Agency decides to manage this challenge is critical to understanding the final risk posture of the delivered system. For example, as demonstrated in the CCP, maintaining a strong competitive environment is critical for the ability of the Agency to influence the design and testing content of a commercial service contracting relationship. But carrying two or more providers also stresses the budget, putting successful program completion at risk.

NASA has to carefully weigh both pros and cons of competition versus resource availability and the impacts on risk posture and safety. Involving multiple commercial providers in the HLS program clearly has strong positives—it leverages the innovation of private "new space" companies to NASA's advantage and provides a broad, inspiring goal to energize and support the overall U.S. aerospace industry. However, carrying multiple potential providers must be deliberately handled in such a way that the overall safety and mission assurance of the Artemis campaign is not undermined by too-tight budgets and incoherent schedules. Warning signs of an acquisition strategy that is amplifying risks would include flight element programs that have begun to decouple from each other and a subsequent diminished emphasis on enterprise SE&I.

In general, clarity of budget, regardless of the competitive posture, is important to ensuring that critical system design, testing, and verification activities are made with long-term operational objectives in mind. Managing in unstable budget environments creates pressure to meet the immediate needs of managing system design and testing requirements at the risk of increased operational complexity, which has the potential to add risk to the overall program. Having a coherent, consistent, well-thought-out and clearly articulated acquisition strategy tied to realism in budget and schedule expectations is important for NASA to manage the overall risk posture for the Artemis campaign.

2. End-to-end software integration.

While integrated software design, development, and testing is clearly a subset of the activities typically addressed in an SE&I plan, the Panel feels strongly enough about the importance of this topic to highlight it for emphasis. The Agency has recently had the opportunity to (re)learn many lessons about the importance of an integrated, accountable, and well-verified approach to software design, development, and deployment. As the Agency has worked to transfer these important lessons to the lunar exploration campaign, it is finding constraints on how the lessons can apply in other areas due to structural and organizational factors instantiated at the beginning of the programs. As the overall Artemis baseline is shaped, the Agency should ensure that all of the lessons learned, and in particular those pointing toward the importance of end-to-end integrated software testing and development, are incorporated as the AES program takes shape.

3. Human-rating process.

The Agency has incorporated many of the lessons learned from the CCP as it preemptively examines and negotiates the path for each provider toward the final human-rating of their systems. The Panel applauds this proactive approach, which sets expectations and discusses potential issues at the beginning of the design phase in order to mitigate as many risks as possible from potentially appearing as "late surprises" in detail design and integration. However, because of the current phase of the program, the Panel will continue to follow this topic with interest and learn more about how the program plans to address the complexities of human-rating a system that is being designed for environments with which the Agency itself has lost much of its experience base. An example of the importance of understanding design and risk posture inter-relationships is the ongoing discussions about the design and delivery of the EUS. The ICPS, originally not designed to human-rating specifications, was modified for human use to support the Artemis-II mission schedule—a risk accepted only for limited use pending the delivery of the EUS, a system designed specifically for human use. The risk posture for the exploration program changes significantly should NASA be unable to procure the EUS. Specifically, the EUS has the appropriate level of micrometeoroid and orbital debris (MMOD) shielding and structural design as well as communication and telemetry redundancy, including fault detection, to ensure the proper level of system health monitoring for human use. In addition, the increased performance and payload capability simplify mission operations, providing additional avenues for risk mitigation. **Figure 8** highlights some of the differences between the ICPS and the EUS. The Panel will be closely watching the integrated risk evaluation and the contribution to that risk from the ICPS as the discussions about EUS schedule and funding continue. As the human lander system designs evolve, NASA will need to understand and track similar types of inter-related design, safety, and risk factors.

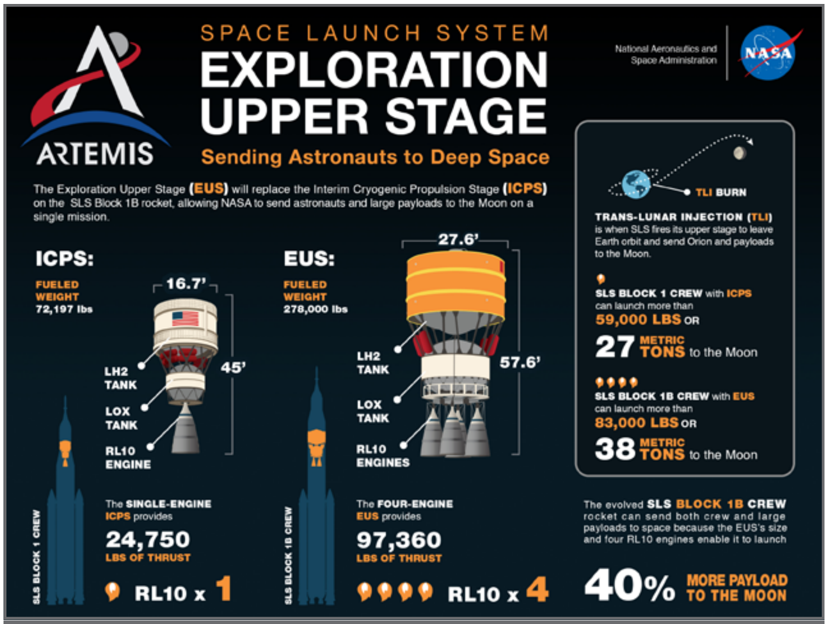

FIGURE 8. Comparison between the ICPS and EUS

4. Human health and performance.

The Panel is very interested in the human health and performance risks attending exploration-class missions beyond LEO. We appreciate the maturity achieved in the design and implementation of NASA's Crew Health and Performance Lifecycle approach. According to the NASA approach, health risks are attributable to five main human system stressors: altered loading, closed environment, radiation, isolation and confinement, and distance from Earth. Looking forward, this framework will aid NASA in addressing the risks through a disciplined, objective approach to data collection and assessment.

NASA recognizes health and medical system requirements can be difficult for designers and developers to accommodate and meet in human space flight systems. Part of the perpetual challenge attending these requirements is a lack of familiarity among developers of the evidence base supporting them. In response, NASA health and medical authorities have developed tutorials accompanying each health and medical standard and requirement to inform system designers, developers, and operators about the relevant human health risks and evidence base. This facilitates better understanding and mitigation of human health risks through all programmatic phases. In addition, from a risk-acceptance perspective, NASA understands that exploration missions will not necessarily allow for options to quickly return the crew home in emergency "life or limb" situations, as has been the health risk management practice for the Apollo, Space Shuttle, and ISS programs. To help manage and understand risk for exploration missions operating in a different medical paradigm, NASA is reviewing existing health standards and, based on decades of evidence, either discarding or revising standards to ensure that health risks are more precisely defined and understood. The radiation exposure standard, for example, informed by longitudinal crew health data, is likely to be relaxed, which will permit more individual astronaut flight opportunities and further enable exploration-class missions. The Panel looks forward to specific briefings on the radiation standard in the coming year.

The Panel believes it is important that NASA continue to gather data on the potential long-term health effects related to longer-duration flight and flight beyond LEO in order to develop a clearer understanding of the health consequences, both short- and long-term, of space exploration and inform future health and medical standards. NASA has an occupational health approach for astronaut health and the option for astronauts who develop health problems to seek remediation through the occupational health program per the TREAT Astronauts Act. The Panel would like to hear more about this going forward, including implementation status reports. The Panel also believes it is best to ensure availability of adequate and accessible health care for crewmembers accepting the risks of human space flight.

5. Workforce.

The workforce issues raised previously in this report are especially applicable to the AES program. As the Agency defines the path to the Moon, it will need to think carefully about the requirements and skill sets, as well as expectations, that it is asking from its workforce. Clarity on these topics ensures that the accountability chain is well understood, and that risk is being managed appropriately. In addition, with clear roles and responsibilities defined, NASA will be able to drive the workforce in the direction of skill sets that will sustain—and be available for—future programs.

C. Commercial Crew Program

The CCP has continued to make substantial progress toward qualifying and certifying two different crew transportation systems to LEO and the ISS.

The most visible achievement this year was when SpaceX launched astronauts Robert Behnken and Douglas Hurley to the ISS on May 31. At the conclusion of a successful mission, both astronauts safely returned to Earth on August 2. This has now been followed by a second successful launch of four astronauts to the ISS (NASA astronauts Shannon Walker, Mike Hopkins, and Victor Glover as well as Japan Aerospace Exploration Agency astronaut Soichi Noguchi), which docked with the space station on November 16. **Figure 9** shows the SpaceX Dragon Capsule approaching the ISS just prior to docking.

Perhaps the single item that has been most different about the CCP when compared with more traditional NASA human space flight programs is the fact that the basic design, engineering, and

FIGURE 9. SpaceX Dragon docks to the ISS

development process has been carried out primarily by industry. This commercial aspect requires safety certification by NASA to carry astronauts under NASA's CCP transportation services contract. This certification process—as developed by the CCP, and which has evolved over the years—is considered to have been successful and may be used as a model, at least in part, for future commercial space efforts. SpaceX, one of the two CCP contractors, recently completed the process and has now been certified to begin its mission of space transportation. The remaining contractor, Boeing, is expected to complete their certification in the coming year following orbital testing, including docking with the ISS.

The CCP, like all development programs, has not been without technical issues. Examples include concerns with COPVs, parachutes, abort systems, sub-system issues, and, most recently, a serious problem with operational software integration. These problems with one or both contractors caused the CCP to develop new methods for working with the contractors on developing and then approving their solutions. In all cases, although much, if not all, the direct work was carried out by industry, NASA was deeply involved in the problem investigation and retained approval authority of the implemented solution and/or the acceptability of the resulting design changes.

The most recently discussed concern refers to the software integration problem that occurred in the Boeing Starliner OFT-1. In this test, the Starliner system encountered several software-driven problems that threatened its operation and could have resulted in loss of the spacecraft. In addition, the command link to the Starliner suffered from several outages during the mission, thus at times preventing proper communications with Mission Control. To fully investigate and develop solutions to these problems, NASA and Boeing formed a Joint Independent Review Team (JIRT). This resulted in 61 recommendations for flight software and mission data loads. In addition to those recommendations covering the flight software issues, 19 additional recommendations were provided, based on the command link outage. Figure 10 illustrates the Boeing Starliner capsule under work in preparation for a second OFT.

FIGURE 10. Boeing Starliner in preparation for a mission

The Starliner Program has worked closely with the JIRT and now fully understands each recommendation and is developing actions to address all items. The program team has closed the loop with the JIRT to ensure their action plans fully meet the intent of the JIRT recommendations. Once JIRT concurrence is obtained, the action plans are resource-loaded, with completion dates tied into the overall schedule. The Panel believes that the processes for resolving and validating these problems should continue to be a watch item because while progress is being made, the effort is still underway.

Another observation made by the Panel concerns the level of insight that the Agency has on the contractors' design activity relative to the risk that is being taken. As NASA evolves into more commercial space activity, it becomes apparent that if NASA is to truly "hand off" work to industry, the issue becomes exactly how deep should their involvement be in the work effort. The extreme of simply acknowledging that something has been done is unlikely to provide sufficient assurance of compliance to certification requirements. However, in order to take full advantage of the speed and innovation of industry, NASA will most likely have to make some changes to their system design and acquisition processes. The trade-off balance remains a key future issue.

One important outcome of this commercial approach is that it did require fewer resources on the part of the Agency to accomplish the task. This allowed the Agency to maintain two contractors through the entire process, giving them the assurance of service provided by having two systems available for transportation. This protects NASA's ability to assure that the ISS is properly crewed, even if one of the providers should have a future issue or incident.

D. International Space Station

The ISS continued its remarkable journey, reaching 22 years in orbit and 20 years of continuous human presence in space in 2020. Four crew expeditions spanned the year, from Expedition 61 through Expedition 64 (shown in **Figure 11**) with 18 crewmembers from the United States, Russia, Italy, and Japan. Through their work, the ISS is closing in on a major milestone of nearly 3,000 investigations conducted onboard, documented in over 2,000 scientific publications, and with contributors from 108 countries.

Every year of the ISS's mission in orbit expands the global experience base in maintaining critical permanent systems in space and in better understanding the human health risks associated with increasing flight durations. As just one example, the results of a research study conducted on the ISS entitled *Assessment of Jugular Venous Blood Flow Stasis and Thrombosis During Spaceflight* were briefed to the ASAP early this year. Findings included stagnant and retrograde blood flow in the internal jugular system of about half of the astronauts participating, with evidence of thrombosis in two astronauts. Whether or not this is associated with a known and not yet fully understood condition, Spaceflight Associated Neuro-ocular Syndrome, and its relationship to intracranial hypertension, is unknown and is under investigation. However, the Panel recognizes the imperative of maximizing the health observation and research potential of the ISS (shown in **Figure 12**) as the best opportunity to discover and mitigate health risks prior to exploration-class missions to the Moon and to Mars.

FIGURE 11. (Top to bottom) Expedition 61 crew, Expedition 62 crew, Expedition 63 crew, and Expedition 64 crew

The Panel had been concerned for some time about the limited capability for a controlled ISS deorbit after a worst-case ISS failure that leaves the vehicle untended by an onboard crew. The Panel commends the ISS program for its work in both studying and preparing capabilities for a controlled deorbit at the end of life and in response to a significant failure like a rapid cabin depressurization. Onboard software has been updated to optimize failure response, attitude control, and altitude management (deorbit burns). Future work includes further propellant management studies, studies and potential additional software for multiple ISS configurations and deorbit burn attitudes, and more. Although the Panel is monitoring the continued work, Recommendation 2012-01-02: ISS Deorbit Capability has been closed.

As a way of staying ahead of events, the Panel recommends that NASA document the ISS life-limiting systems and components—through and beyond 2028—which are considered by test, analyses, or engineering judgment to be of highest risk to ISS lifetime, as defined by both critical functions and time to effect (i.e., which have the worst impact and occur soonest). The Panel also recommends that NASA assess the engineering lead time required to develop and fly solutions to the highest risk failures if they were to occur before 2028. Further, if extending the ISS beyond 2028 should be required for longer-term LEO presence and/or commercialization, this assessment should be updated early enough before 2028 to support initiating any development and manufacturing required as a result of these high-risk items.

Related to ISS lifetime is the continued ability to operate and maintain all systems onboard. NASA has taken steps to ensure U.S. extravehicular activity (EVA) capability by refurbishing and re-flying extravehicular mobility units (EMUs) and, in parallel, has

FIGURE 12. The ISS continues to serve as an outstanding platform for research in LEO

flown development hardware for the new Next Generation EMU (xEMU) that is planned for Artemis missions. However, with the delay in Commercial Crew missions, the ISS crew had been reduced to only three crewmembers since the start of Expedition 62, obviously halving the crew time available to do all work, from maintenance to utilization. It also posed a challenge for scheduling EVAs. Although the crew had the training necessary to conduct contingency EVA and robotic operations if required in response to a failure, previously scheduled U.S. EMU EVAs—like the series of U.S. electrical system battery replacements—were put on hold until Doug Hurley and Bob Behnken were onboard in June and July during SpaceX Demo-2. Although the crew size increased to seven when SpaceX Crew-1 arrived on November 16, a related ASAP action remains open (2018-04-02: Action to Ensure U.S. Access to the International Space Station Given Commercial Crew Program Schedule Risk).

The Panel therefore advises NASA to consider sustainable solutions in the event of continuing operations after any unplanned reduction in crew size—for instance, if there is a gap between the departure of Crew-1 and the arrival of Crew-2. The intent is to ensure that the critical crew skill sets are onboard at all times. For example, manifesting every crew rotation flight to have at least one U.S. and one Russian crewmember onboard to facilitate this kind of "insurance." In any case, the Panel advises NASA to resolve this recurring risk as part of normal practice and not on an increment-by-increment and ad hoc basis.

As reported in last year's annual report, in 2018 the ISS experienced a cabin pressure leak, later reported to have been caused by a hole that had been drilled through the wall of the orbital module of a docked Soyuz spacecraft. In August 2020, while following up on a separate cabin pressure leak, the ISS crew identified the source of this leak as a "crack" in the Service Module aft vestibule and applied Kapton tape in an unsuccessful repair attempt. The Panel has not seen details and, in both cases, encourages the Agency to confirm that the root cause is understood and corrective actions have been taken to mitigate future risk.

As part of NASA's evolving efforts to commercialize LEO, the Agency is both assessing and negotiating allowing commercial astronauts to have access to the ISS. These would be a combination of private company employees and customers. As mentioned in Section III, NASA's Human Space Flight Evolution, the ASAP encourages the Agency to take deliberate steps to evaluate and communicate the risk-benefit value proposition for permitting commercial astronauts and customers onboard. This includes managing risks to the ISS and crew when onboard, and also any consideration for higher risks, e.g., use of hazardous materials, robotic operations, and EVA. The Panel looks forward to exploring NASA's process to evaluate and manage these risks.

VIII. Space Traffic Management

A. Background

MMOD has become a major safety issue, not only for NASA, but also for the entire international space community. For example, the potential hazard from MMOD is the dominant contributor to calculations of loss-of-crew predictions for Dragon, Starliner, and Orion, and it has been a factor in two of the top three safety risks for the ISS. Because of the impact on space safety and the need for urgent action on the part of the U.S. government, the ASAP recently made a number of specific recommendations for both Congress and the NASA Administrator on how to respond to this important issue.

B. Why Action is Needed Now

Space is becoming more congested. For example, CubeSats and other small satellites are being launched by private companies and academia with increasing frequency, and several companies are now deploying "mega-constellations" with hundreds or even thousands of satellites. In addition, more countries than ever before are engaging in the use of space and in launching space assets to meet their national objectives. Meanwhile, the U.S. Department of Defense (DOD) is attempting to keep track of objects in space, and although the DOD currently executes a "space collision" warning process in the interest of national security, being a "space traffic cop" is not part of their core military mission. A complicating factor is that no universally accepted "rules of the road" exist for the safety of space operations, much less a regulatory regime for active risk management and collision avoidance. As the potential for orbital collisions rises with increasing congestion, it is important to recognize that risks to astronauts, critical national security capabilities, and global space commerce are also on the rise, to the extent that the use of some orbital regimes may become impractical due to debris density. **Figures 13 and 14** below illustrate the continuing increase in the number of objects being tracked, as well as the total mass of all objects currently in orbit. The sudden increase in orbital objects in 2007 was caused by a Chinese anti-satellite test, an action that resulted in more than 2,000 new pieces of trackable

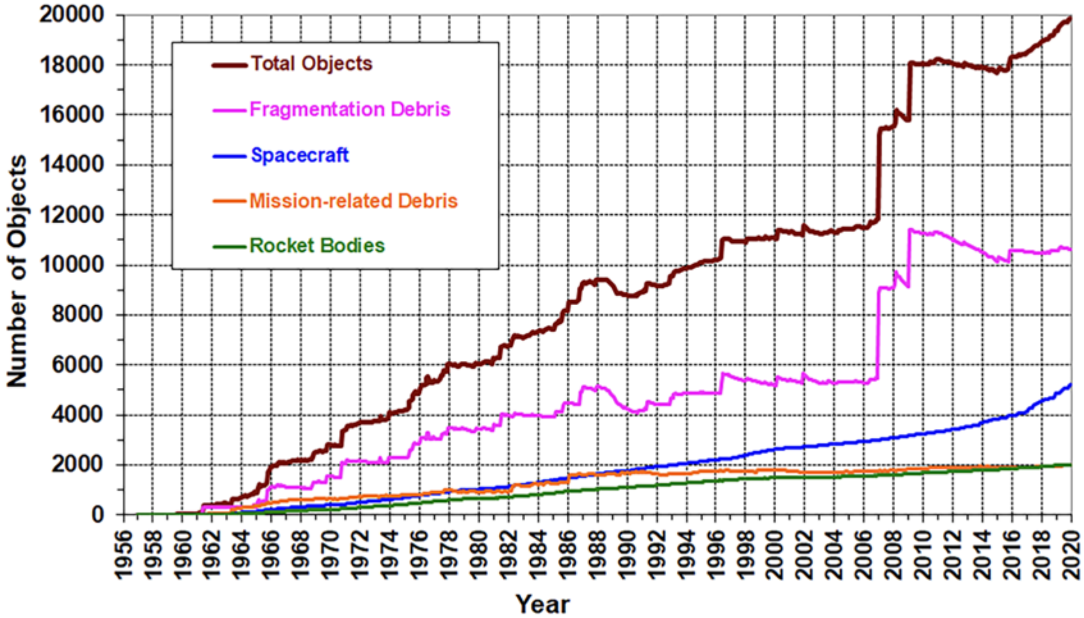

FIGURE 13. Number of objects being tracked in orbit continues to increase

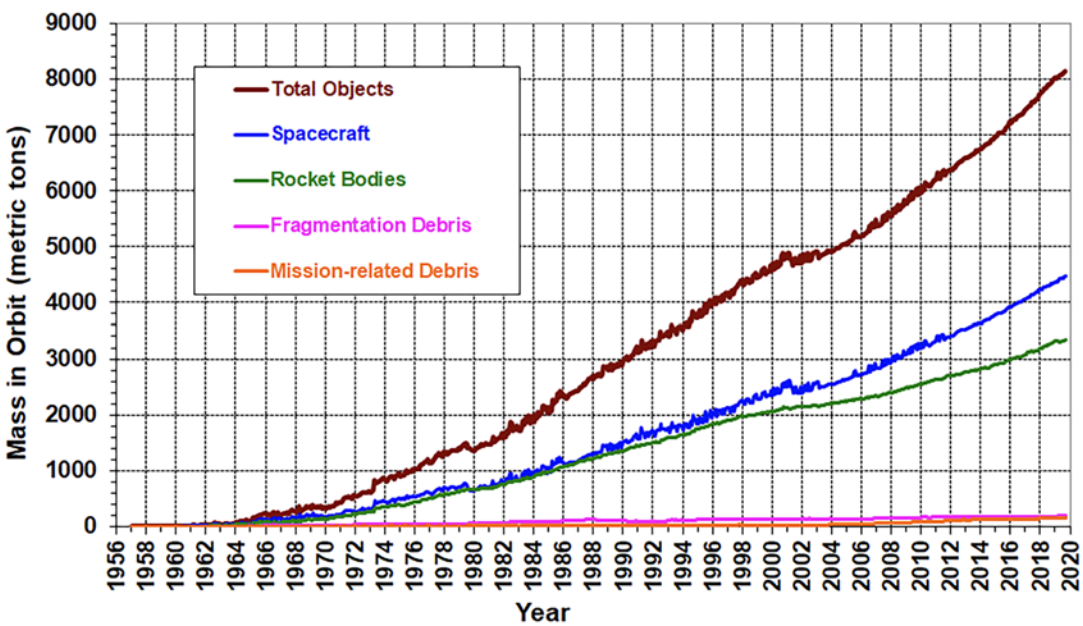

FIGURE 14. Total mass of all objects in orbit currently exceeds 8,100 metric tons

orbital debris. The spike in 2009 was a consequence of an accidental collision between Iridium 33, an operational U.S. commercial communications satellite, and Cosmos 2251, a non-functional Russian communications satellite, that resulted in more than 1,000 pieces of trackable debris.

C. Outer Space Treaty

The Outer Space Treaty, which has been ratified by the United States and over 100 other nations, is widely considered to be the foundation of international space law. Article VI of the Treaty states that "the activities of non-governmental entities in outer space…shall require authorization and continuing supervision by the appropriate State Party to the Treaty." Exactly how those activities are to be authorized and continually supervised is left to the judgment of the individual national governments; however, Article VII states that the signatories are "internationally liable" for any damage that might be caused to other spacecraft.

D. Existing Regulatory Framework

In the United States, responsibility for overseeing and regulating commercial space activities is shared by several different organizations. However, those responsibilities do not include regulating the risks of orbital debris. The Federal Aviation Administration is responsible for licensing commercial launches and reentries. The Federal Communications Commission is responsible for licensing radio broadcasts from space. The National Oceanic and Atmospheric Administration is responsible for licensing remote sensing operations, such as taking pictures of Earth. The DOD and NASA are key players in space, but they are not regulatory agencies. In the past, most commercial space activities have involved either telecommunication satellites of one kind or another or Earth observations, so this basic division of regulatory responsibilities has not been a problem. However, given the recent increase in non-traditional commercial space operations, including satellite servicing, space tourism, and the deployment of large numbers of satellites to provide worldwide internet access, updates to the existing roles and responsibilities may be appropriate. As things stand today, there are no clear lines of authority for directing coherence among the many entities that operate in space.

E. MMOD and Space Traffic Management Recommendations

At its Third Quarterly Meeting of 2020, the ASAP adopted several specific recommendations (2020-03-01 and 2020-03-02) related to Space Traffic Management. Following the meeting, the recommendations were formally submitted to Congress and to the NASA Administrator, respectively.

Recommendations for Congress:

- Designate a Lead Federal Agency for Civil Space Traffic Management.
- Provide that agency with authority, immunity from lawsuits, and resources to do the job.

- In addressing the Space Traffic Management issue, require whole-of-government engagement, public-private partnerships, and collaboration between government, industry, academia, and the international community.

Recommendations for the NASA Administrator:

- Support and partner with the Lead Federal Agency once one is selected.
- In the interim period:
  - Because of the direct relationship to astronaut and spacecraft safety, ensure that risks having to do with MMOD, Space Situational Awareness, and Space Traffic Management are addressed in NASA's ongoing activities and in future budget requests.
  - In collaboration with other government agencies and industry, develop and publish guidelines for Space Traffic Management focused on current and emerging challenges to maintain the safety of astronauts and spacecraft.
  - Develop a proposal for a Space Traffic Management technology roadmap.

F. Recent Developments

On August 20, 2020, the National Academy of Public Administration issued a report titled *Space Traffic Management: Assessment of the Feasibility, Expected Effectiveness, and Funding Implications of a Transfer of Space Traffic Management Functions*. Congress had directed the Office of Space Commerce (OSC), a part of NOAA within the Department of Commerce (DOC), to contract with NAPA to perform the study. The purpose of the study was to examine which government organization should assume the mission of Space Traffic Management. The study's conclusion was that the OSC was best suited to take on this responsibility.

Following publication of the NAPA report, the chairman of the Senate Committee on Commerce, Science, and Transportation introduced the Space Preservation and Conjunction Emergency (SPACE) Act. The legislation would authorize the DOC to provide space situational awareness services to civil, commercial, and international space operators—a first step toward cohesive actions that would manage risk across the space operations "ecosystem." It should be noted that, if the SPACE Act is eventually approved by Congress and signed into law by the President, it would still be necessary for Congress to provide the OSC with the necessary budget and staffing resources through the appropriations process before it would be able to take any significant actions to implement the Act.

Meanwhile, close calls continue, even for the ISS. To date, the ISS has conducted three collision avoidance maneuvers during 2020, including one on September 22, when the astronauts were requested to move to the Russian segment during the close approach of an unidentified piece of debris. These collision avoidance maneuvers have become much more frequent in the last 15 years, based on a significant increase in the number of objects in LEO.

IX. NASA's COVID-19 Pandemic Response

NASA responded early and effectively to the COVID-19 pandemic threat. The Office of the Chief Health and Medical Officer (OCHMO), leveraging data from the Department of Homeland Security, began tracking the emergence of the virus in China during January 2020. The Chief Health and Medical Officer informed NASA senior leadership of the pandemic threat, and by mid-February the Agency was updating existing pandemic plans to deal with this highly infectious viral pathogen.

NASA rapidly worked with sister agencies and academic institutions, such as the Mayo Clinic, to develop and implement a staged response plan to community viral burden arising in and around NASA Centers. NASA senior leadership established a multidisciplinary COVID-19 response team, led by the Acting Deputy Associate Administrator. Agency and Center-level response plans were developed and implemented, along with weekly senior leadership COVID-19 meetings Agency-wide. NASA implemented mandatory telework at the Ames Research Center by the second week of March 2020, and the rest of the Agency followed as pandemic conditions required. The NASA Administrator and all senior leaders have been highly visible and supportive of the pandemic response, resulting in very effective interdiction of the viral threat at all NASA facilities.

NASA worked quickly to implement multiple coordinated control measures. The Agency directed masking and social distancing in all public spaces and instituted case investigation and contact tracing, assisted by an internally developed application. NASA also maximized facility air exchanges with high-efficiency particulate air filtration and leveraged screening technologies to reduce the risk of viral entry and transmission. NASA employed automated kiosks, which screened employees for temperature elevation and COVID symptoms. The Agency continues to evaluate wearable technology to monitor respiration and pulse rates, as elevation of pulse and respiration rates often precede symptom development and can potentially detect asymptomatic transmitters. In addition, NASA industrial hygiene teams developed procedures and implemented technologies for surface sanitation and facility hygiene and established administrative controls to enhance social distancing.

The OCHMO, in coordination with the Chief Information Officer, integrated data from local public health authorities and health care systems proximate to NASA Centers and created a data dashboard, similar to those of the Centers for Disease Control and Prevention (CDC), Johns Hopkins University, and many states, aiding NASA decision-making at multiple levels.

Notably, NASA also turned to its innovation capability to help address national pandemic needs and shortages. A Jet Propulsion Laboratory team designed a small ventilator, built a prototype, and achieved Food and Drug Administration certification in 37 days. NASA and Virgin Galactic collaborated to develop a continuous positive airway pressure helmet to help severely ill COVID patients avoid mechanical ventilation. Wearable technology to detect early signs of health compromise, 3D printing (personal protective equipment), collaboration with National Institutes of Health/CDC for supercomputing to support pandemic modeling, and leveraging environmental monitoring technology to attempt early disease detection are other examples of NASA's direct contribution to the pandemic response thus far.

In summary, NASA, with the full support of senior leadership, adapted its health care and administrative support systems to develop a first-rate public and occupational health response to the pandemic. The virus has taken a toll, however. There have been cases of COVID-19 among NASA civil servants and contractors since the pandemic began. The vast majority of cases are due to community transmission, with very little evidence of disease transmission in NASA facilities. Unfortunately, there have also been COVID-related deaths among the NASA contractor workforce. The pandemic has had ongoing negative impact to every human space flight program as well, including the continuing limitations of on-site work, increased costs, work inefficiencies, and schedule delays.

Considering the degree of community transmission proximate to many NASA Centers, the Agency's pandemic response has been very successful. We all hope for a rapid and effective COVID-19 vaccine distribution program, but this will take months, at best, to have a significant positive impact at the population level. The Panel commends NASA leadership and the NASA team for this collaborative pandemic mitigation effort at the Agency level, which will likely need to continue for the immediate and foreseeable future.

X. Summaries of Key Issues and Program Assessments

Six key issues that were identified in this report have been summarized in the table below to emphasize their importance to the Panel.

Summary of Key Issues

Topic	Key Issues
NASA Evolution	Because NASA's ability to directly affect mission safety and success necessarily evolves with its changing role from executor to buyer, the ASAP recommends the Agency take very deliberate and transparent steps to explicitly consider the risk/benefit trades to each "partnership," communicate expectations consistent with each partnership, and establish management practices that reflect and deliver on those expectations. More specifically, if NASA intends to evolve further into "buying" its highest-risk flight elements and mission services in human space flight exploration rather than "executing" the Agency's more developmental programs, the Panel recommends that NASA and its stakeholders deliberately take the steps needed to manage the associated development, testing, and operations.
Systems Engineering and Integration	Whatever acquisition strategies NASA chooses to pursue for the overall Artemis campaign, adherence to proper SE&I principles must be codified, written into contracts, reflected in NASA's management processes, and transparently communicated as expectations to the NASA organizations and NASA's stakeholders. The roles, responsibilities, and authorities for the entire hierarchy of SE&I execution cannot be left open to interpretation. The decision processes for risk management throughout the entire "ecosystem" of the Artemis campaign—and across the development timelines of every contributing program—must be well integrated, consistently applied, and fully transparent.
Workforce	The evolution of NASA's missions, management roles, and acquisition strategies is having and will likely continue to have effects on NASA's workforce of government and contractor employees. The new paradigm of roles, responsibilities, and technical authorities will need to be communicated with complete clarity and codified in contractual vehicles. To retain its required technical expertise and ensure risk is appropriately managed in future complex human space flight programs, NASA will need to deliberately address workforce issues at the strategic level.
Constancy and Support of Purpose	Safe and successful execution of human space exploration depends on well-defined and constant purpose; technical baselines and schedules that are mutually consistent, realistic, and achievable; and adequate and stable resources.
Space Traffic Management	Congress should designate a Lead Federal Agency for Civil Space Traffic Management and provide it with the necessary authority, immunity from lawsuits, and resources to do the job. NASA should support and partner with the Lead Agency once one is selected. In the interim period, NASA should continue to address the risks having to do with orbital debris, space situational awareness, and space traffic management in its ongoing activities and future budget requests.
Human Space Flight Mishap Response	As first discussed in the ASAP's 2015 Annual Report, the language in the NASA Authorization Act of 2005 must be reviewed and updated to be compatible with current commercial space systems and operations.

Summary of Program Assessments

The following table provides a summary of the Panel's assessments of the major NASA programs that were evaluated during the year.

Program	Assessment
Exploration Systems Development	Despite the global pandemic and several severe weather events, the ESD program is making impressive progress toward completion of all required tests, including the Green Run. The ASAP is monitoring some issues that may affect risks related to ESD, including whether reliability enhancements to the ESM propulsion valves were successfully implemented. A recent issue that the ASAP will be following involves a failure that was detected in the redundant channel of a power and data unit controller located in the Orion Crew Module Adapter. NASA has decided to fly the capsule as is rather than taking several months to remove and replace the failed component.
Advanced Exploration Systems	As NASA defines and initiates the acquisition strategy, architectural framework, and program structure for the long-term Artemis campaign, the Agency should ensure that clear roles and responsibilities are delineated, specifically related to the SE&I function. An SE&I approach with clear accountability is necessary to manage risk across the complete enterprise, especially given the meager experience base related to sending humans beyond LEO. Another important factor for risk management is ensuring that the lessons learned from the previous programs, including both the CCP and ESD acquisition approaches, are incorporated into the Artemis strategy.
Commercial Crew Program	The program continued with its effort to certify two separate vendors to provide transportation of NASA astronauts to the ISS. One contractor, SpaceX, completed its crewed operational flight test with a successful launch and recovery of two astronauts to the ISS. Subsequently, they conducted their first operational crew transportation launch, delivering four astronauts to the ISS for a full-duration stay. Due to the completion of these flights, the Agency has now certified the SpaceX system. Boeing, the second contractor, developed a software integration and communication link issue during their uncrewed flight test, with potentially serious consequences. NASA and Boeing are now fully engaged in building up to a retest and solving these issues, and it is likely that they will complete their certification in 2021. The Panel observed that NASA still has an issue relative to defining its required level of insight versus the level of risk being taken, and it is most likely that this will remain a Panel watch item for the future.
International Space Station	The Panel advises NASA to consider sustainable solutions for continuing operations after any unplanned reduction in crew size—for instance, if there is a gap between the departure of Crew-1 and the arrival of Crew-2 [2018-04-02: Action to Ensure U.S. Access to the International Space Station Given Commercial Crew Program Schedule Risk]. The Panel has not seen details for either the Soyuz or ISS Service Module cabin leaks and encourages the Agency to confirm that the root cause, in both cases, is understood and corrective actions have been taken to mitigate future risk. The ASAP encourages the Agency to take deliberate steps to evaluate and communicate the risk-benefit value proposition for permitting commercial astronauts and customers onboard the ISS. This includes managing risks to the ISS and crew when onboard, as well as any consideration being given to higher-risk activities, e.g., the use of hazardous materials, robotic operations, or EVAs.

APPENDIX A

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

2020 Recommendations[1]

2020-03-01 Designation of a Lead Federal Agency for Civil Space Traffic Management (Congress)

Finding: For several years, the Panel has expressed concern with the risk of damage to orbiting spacecraft and transiting astronauts due to micrometeoroids and orbital debris (MMOD). The hazard from MMOD has been recognized as a major issue in every program. MMOD is the dominant contributor to the calculations of loss-of-crew predictions for both commercial crew vehicles and Orion, and it has been a factor in two of the top safety risks for the International Space Station (ISS). NASA declared it an Enterprise Risk in 2017.

Recommendation: The Panel recommends that the Congress:

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

Rationale: The hazard persists and continues to grow exponentially. Space is becoming more congested. For example, CubeSats and other small satellites are being launched with increasing frequency,

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, or that there is no identified resolution. Yellow highlights an important ASAP concern or issue that we are not confident is being addressed adequately, 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 but continues to be followed by the Panel. No color indicates that the ASAP has not received a response.

and several companies are now deploying mega-constellations with hundreds, or even thousands, of satellites. Some of these satellites incorporate the use of electric propulsion and autonomous onboard maneuvers with very short turnaround times, increasing the difficulty of tracking and planning for collision avoidance.

It is important to recognize the prevalence of the issue. Orbital debris events and close calls are not rare, but they are in fact becoming more and more frequent as space becomes more congested and as national and international space players—who rightfully seek to leverage the high ground of space for commerce, science, and national prestige—continue to populate the space domain with new satellites. The risks are growing, and a more strategic approach to the problem is now necessary to arrest the risks and to assure that the domain of space remains sustainable.

NASA currently has 20 missions in Low-Earth Orbit (LEO), and the Agency definitely takes the risk seriously. But the issue is larger than NASA—it affects and is affected by all entities that conduct operations in space, and it endangers all of those functions on which the public has come to rely—communications, navigation, weather prediction, to just start the list. While the ASAP is principally focused on the serious hazards to NASA spacecraft and astronauts, the Panel recognizes that the issue must be tackled on a broader front.

The Panel was encouraged in 2018 when the National Space Council issued Space Policy Directive-3 (SPD-3), the National Space Traffic Management Policy, which acknowledged and addressed this issue and the need to improve Space Situational Awareness and Space Traffic Management. SPD-3 promoted the implementation of a number of steps to address the orbital debris risk and recommended that the Department of Commerce take responsibility for implementing a Civil Space Traffic Management framework. The Panel is dismayed that Congress and the Administration have not yet reached an agreement on the appropriate response to that recommendation, resulting in departments and agencies not being able to move forward on implementing a framework that will both materially reduce the Space Traffic Management risks and increase the sustainability of space as an international strategic domain.

It is well overdue that the United States exert some effective international leadership in the safety of space operations and begin doing so by designating—including providing authority and resources to—a Lead Agency to see to the provision of timely and actionable safety data to all space operators; work proactively within government, with industry, and in partnership with the international community in developing standards, guidelines, best practices, and "rules of the road" for safe space operations; and support the conduct of scientific research and technology development for related areas, such as improved sensors, software, constellation management techniques, and methods for active debris management.

OPEN The chairman of the Senate Committee on Commerce, Science, and Transportation has introduced the Space Preservation and Conjunction Emergency (SPACE) Act, which would authorize the Department of Commerce to provide space situational awareness services to civil, commercial, and international space operators. However, even if the SPACE Act is eventually approved by Congress, and signed into law by the President, it would still be necessary for Congress to provide the necessary budget and staffing resources through the appropriations process before any significant actions could be taken to implement the Act.

2020-03-02 Designation of a Lead Federal Agency for Civil Space Traffic Management (NASA)

Finding: For several years, the Panel has expressed concern with the risk of damage to orbiting spacecraft and transiting astronauts due to micro-meteoroids and orbital debris (MMOD). The hazard from MMOD has been recognized as a major issue in every program. MMOD is the dominant contributor to the calculations of loss-of-crew predictions for both commercial crew vehicles and Orion, and it has been a factor in two of the top safety risks for the International Space Station (ISS). NASA declared it an Enterprise Risk in 2017.

Recommendation: The Panel recommends that NASA:

- Support and partner with the Lead Federal Agency once one is selected.
- In the interim period:
  - Because of the direct relationship to astronaut and spacecraft safety, ensure that risks having to do with MMOD, Space Situational Awareness, and Space Traffic Management are addressed in NASA's ongoing activities and in future budget requests.
  - In collaboration with other government agencies and industry, develop and publish guidelines for Space Traffic Management focused on current and emerging challenges to maintain the safety of astronauts and spacecraft.
  - Develop a proposal for a Space Traffic Management technology roadmap.

Rationale: The hazard persists and continues to grow exponentially. Space is becoming more congested. For example, CubeSats and other small satellites are being launched with increasing frequency, and several companies are now deploying mega-constellations with hundreds, or even thousands, of satellites. Some of these satellites incorporate the use of electric propulsion and autonomous onboard maneuvers with very short turnaround times, increasing the difficulty of tracking and planning for collision avoidance.

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OPEN NASA's response not provided at time of ASAP Annual Report 2020 printing.

Open Recommendations from Prior Years

2019-02-01 Required Transition to Next Generation Extravehicular Mobility Units (EMUs)

Finding: The ASAP has become increasingly concerned with the risk posture that NASA has adapted regarding the current EMUs used in International Space Station (ISS) operations, and has concluded that the current EMUs are now outside their design life.

Recommendation: NASA should begin an immediate transition to a next-generation Extra-Vehicular Activity (EVA) suit system EMU, before the risk to EVA becomes unmanageable.

Rationale: It is an undeniable fact that the 40-year-old EMUs used in ISS operations are reaching the end of their useful life. The Panel reviewed the increasing challenges of difficult upgrade efforts, loss of component vendors over time, lack of critical refurbishment parts, and life extension analyses that will grow in uncertainty as the suit hardware continues to age. Over the years, the Panel has commented on the highly innovative and often heroic approach that NASA has taken to devise EMU component upgrades and suit life extensions; it has also noted the small but productive steps accomplished by the development program for the next-generation xEMU prototype. The current plan is to extend today's EMU use to 2028; however, it is increasingly apparent that the usable life of the current EVA suits is limited. The Panel encourages NASA to step back from day-to-day management issues to view this urgent issue from a broader, more holistic outlook. The problem does not lie simply in the fact that the suits are old; but the fact that manufacturers of several critical suit components, including the very fabric of the suits, have now gone out of business, creates real urgency for transitioning to new EVA suit systems. New suits are needed not only for future space exploration, but also for its current space activities. NASA cannot maintain the necessary, ongoing LEO operations without fully functional EVA suits.

OPEN NASA responded on 9/11/19, concurring with the recommendation. While NASA has presented plans for the development of the xEMU, including flying a prototype xEMU on the ISS for testing, the xEMU development and acquisition approach is primarily focused on producing suits for the lunar campaign. The Panel has not received information indicating how the current approach to xEMU development and acquisition will mitigate the ongoing risks of extending the current EMUs on ISS to 2028.

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

Finding: 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 Commercial Crew Program (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 qualification and certification testing. The Boeing program also holds key risk items, some of which have emerged during the qualification test program; specifically: parachutes, launch abort engine hot fire testing, and pyrotechnic separation bolt initiator device qualification failures. The burn-down curve of certification products remains fairly steep for verification and validation, 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.

OPEN NASA originally responded on 3/29/19, concurring with the recommendation. NASA continues to work with the commercial providers to obtain valuable data from both crewed and uncrewed test flights in order to minimize risk and correct any emerging issues. The results from the series of reviews for each flight will culminate in a Certificate of Flight Readiness, asserting that the commercial provider has completed all work associated with meeting the applicable requirements, standards (including alternate standards), and hazard reports. The final certification work for SpaceX has been completed and they have moved on to operational flights, just launching Crew-1 and now planning for Crew-2. The certification work continues with the Boeing system and should undergo the same rigorous process of reviewing the results of every flight to assure any issues are worked or corrected. Work will be ongoing into 2021 and beyond.

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

Finding: As outlined in the Finding for Recommendation 2018-04-01, serious technical difficulties and challenges pose considerable risk to both providers' schedules for crew transportation to the ISS in calendar year 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 Commercial Crew Program (CCP) flights with crew, senior NASA leadership should work with the Administration and Congress to guarantee continuing access to ISS for U.S. crew members until such time that U.S. capability to deliver crew to the 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.

OPEN NASA responded on 3/29/19, concurring with the recommendation. NASA is developing options to protect the presence of American crew on the ISS to support the U.S. On-Orbit Segment. During the ASAP's 2020 Second Quarterly meeting, the Panel advised NASA to broaden its approach to this issue and resolve this recurring risk as part of normal practice and not on an increment-by-increment basis. Specifically, consider sustainable solutions in the event of continuing operations with reduced crew capacity that ensure that the critical crew skill sets are on board at all times. For example, manifesting every crew rotation flight, on either U.S. or Russian spacecraft, to have at least one U.S. and one Russian crewmember on board to facilitate this kind of "insurance."

2018-02-01 NASA Safety Assurance Process Scope and Quality (2017-02-01 REVISED)

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 they audited 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 the 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's OSMA 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 is not just a paper drill (a checklist)—it should be what is actually being done. The Panel wants positive confirmation that the OSMA not only has a policy, but that the policy is embraced across the Agency. The Panel is not asking the 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.

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 ongoing performance-based safety and mission success audit process in a State of Capability report. The ASAP reviewed the report and had planned to attend an audit in 2020 to confirm progress. However, with the COVID-19 pandemic, the scheduled audits had to be postponed. When NASA can resume the planned safety and mission success audits, the ASAP will reschedule its attendance at one of the audits.

2017-01-01 Practice of System Engineering and Integration Principles by Commercial Crew Providers for Transportation Services to the ISS

Finding: The investigations into two recent mishaps on commercial launch vehicles have concluded that the mishaps were unrelated because the immediate (or proximate) causes of the mishaps were different. However, in the opinion of the Panel, the underlying root causes of both mishaps can be traced to escapes in the System Engineering and Integration (SE&I) process and controls involving one or more of the following areas: design, analysis, manufacturing, quality control, qualification, and operations (including operational tests).

Recommendation: The 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.

Rationale: Rigorous and disciplined SE&I processes and controls are essential elements of any engineering effort. When dealing with complex systems for human space travel, where inherent risks must be managed to an acceptable level, the emphasis on SE&I and cross-discipline engineering is even more critical. No amount of NASA oversight or insight into the performance of the commercial providers can compensate for a lack of rigor in the providers' SE&I processes and controls. On a regular basis, the commercial providers make numerous important decisions that do not rise to the level of NASA oversight. Their detailed knowledge of the system design, qualification, and performance generally exceeds that of the NASA engineers who provide insight and oversight. Thus, the responsibility for producing a system that provides an acceptable level of risk for NASA missions to the ISS rests heavily on the commercial providers and their SE&I processes and controls.

Finally, it is important for the provider to not only furnish evidence that rigorous, disciplined, and sustainable SE&I processes and controls are in place, but they should also be shown to be effective over time. This is a foundation for all other certification activities.

OPEN NASA responded on 5/22/17, concurring with the recommendation. NASA stated that the 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 requirements, deliverables, and insight, the 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. In addition, the Boeing Orbital Flight Test (OFT) mishap of December 2019 offered additional opportunity for NASA to hone its oversight of SE&I principles. The ASAP will continue to monitor the SE&I practices throughout the development and certification process, and how SE&I "lessons learned" from the CCP promulgate through other human space flight programs.

2016-04-01 Asset Protection—Security Clearance Policy

Finding: NASA is taking a holistic approach to asset protection, linking space asset protection, cybersecurity, and critical infrastructure on the ground. The identification of James Leatherwood as Principal Advisor to the Associate Administrator and establishing an Enterprise Protection Program (EPP) modeled after the Technical Authorities is a positive step. The Panel was gratified to see that NASA is taking a holistic approach and starting down the path of putting in place the management policies and practices to have an effective EPP. While there are many challenges ahead, one of the big challenges to an effective program is having appropriate clearances for the appropriate people in the Agency who make the decisions to protect assets from threats. Currently, there are too many cases where security clearances are lacking. NASA has put in place a system to work around these difficulties, but it is not optimum.

Recommendation: 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 EPP, including the appropriate program managers.

Rationale: The appropriate people in the Agency need to have to have a level of clearance necessary to understand the threat, make the proper decisions, and allocate the proper resources. When a new program manager is coming online, if he or she does not have the appropriate security clearance already, submitting the necessary paperwork may not be high on the new manager's list of tasks. NASA needs a policy to put a high priority on the submission of appropriate clearance paperwork.

OPEN NASA responded on 1/17/17, concurring with the recommendation. In 2019, NASA established clearance requirements within the governance management system of the EPP and reviewed positions, descriptions, and compliances. In early 2020, the Panel requested a summary of the outcomes of this advertised process—specifically, a NASA-wide list of program managers' job descriptions and their current security clearance requirements/status. The Panel will then be able to ascertain the effectiveness of the advertised process to assure that security clearances are appropriately distributed. It is hoped that the outcomes of the 2019 reviews generated appropriately adjusted security clearance requirements for key personnel who have technical authorities and responsibilities, and are accountable for implementing EPP policies, directives, and threat information within their programs.

2015-05-02 Human Space Flight Mishap

Finding: The CCP is now developing a formal plan for how it will respond in the event of a major malfunction or mishap. In addition to optimizing what can be learned by proper investigation of malfunctions or mishaps, this plan must comply with specific language in the NASA Authorization Act of 2005 concerning Human Space Flight Independent Investigations. NASA has tentatively identified the entities that would investigate various types of mishaps during the five mission phases. Under the current Authorization language, a Presidential Commission would be required in all cases involving loss of the flight crew as well as in all cases involving loss of the vehicle, even if the flight crew is not injured. Use of a Presidential Commission in the latter cases appears excessive.

Recommendation: 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.

Rationale: The requirement for a Presidential Commission was logical for the ISS or Space Shuttle missions, because they were reusable national assets. It would, however, appear excessive in some cases for commercially provided vehicles or other vehicles not planned for reuse. One example would be the sinking of a non-reusable vehicle after the flight crew had been safely recovered and were on their way home.

OPEN NASA originally responded on 4/30/16, concurring with the recommendation. The response stated that 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 option in the event of a major malfunction or mishap in the CCP. The ASAP provided a written response on 9/8/17, followed by subsequent discussions during which the ASAP provided alternate solutions to which NASA provided a third response on 3/15/18. NASA and the Congress are still working to establish a satisfactory process to address the concerns previously articulated. The ASAP believes action is increasingly essential and urgent as NASA has already begun launching astronauts on commercially provided vehicles, and the future Artemis missions will be even more complex in their involvement of commercial providers and international partners.

APPENDIX B

Closure Rationale for Recommendations Closed in 2020

2019-04-01 Required Safety and Mission Assurance Technical Excellence Program (STEP) Training for All NASA Personnel

Finding: The NASA Safety Center supports the Office of Safety and Mission Assurance (OSMA) in four major areas: mishap investigation, audits and assessments, knowledge management, and technical excellence. In short, the Center provides a wide breadth and depth of information, from policy to education, pertaining to maintaining and promoting a safety culture. One of the programs available from the Center caught the attention of the Panel: the Safety and Mission Assurance Technical Excellence Program, or STEP. STEP is available as online learning, providing continuing education credits designed to teach safety professionals and the overall workforce about system safety. The program has multiple levels, with the Level 1 curriculum specifically targeted to benefit the engineering workforce. Higher levels provide more advanced content for Safety and Mission Assurance (SMA) professionals.

Recommendation: Given the importance of creating a culture of safety across the NASA workforce, and the availability of a resource to promote that goal, the ASAP would like to recommend that NASA adopt an Agency-wide requirement for all employees to complete the STEP Level 1 training course.

Rationale: There is no requirement across the Agency for the workforce to take the training. SMA professionals are only "encouraged" to enroll in the program. With the exception of Kennedy Space Center, where the STEP Level 1 curriculum is required for all new hires, the general workforce remains largely unaware of the offering.

NASA Response: NASA concurs with the intent of ASAP's recommendation that NASA adopt an Agency-wide requirement for all employees to complete the STEP Level 1 training curriculum in order to foster a culture of safety across the NASA workforce.

A workforce with a strong safety culture is vital to achieving mission success. To that end, NASA began requiring all new civil servants to take the two-hour course *Orientation to Safety Culture* in 2016. The mission of the Agency's Safety Culture program is to create at NASA an environment characterized by safe attitudes and behaviors, open communication and mutual trust, shared lessons and values, and balanced challenges and risks. NASA has a robust safety culture outreach, including safety culture surveys at each Center, awareness material, the "caught doing right" campaign, and "yes if" coins. Additionally, each Center has specific safety training and hosts a safety day to promote various tenets of safety to their workforce.

The *Orientation to Safety Culture* course is part of the STEP Level 1 training curriculum. When considering this recommendation to add 28 hours of the STEP Level 1 curriculum to the training portfolio of the entire NASA workforce, the benefits to the Agency's safety culture must be balanced against the burden of additional mandated training. As a Federal agency, NASA must comply with various Federal training requirements, several of which require periodic reoccurrences of the mandatory training in addition to mandatory training for new hires.

STEP Level 1 training is designed to serve as an orientation to SMA, and while it is a good baseline for SMA employees, it may not be applicable to the entire workforce or relevant to achieving and maintaining an engaged safety culture. After reviewing the learning objectives of each course within the STEP Level 1 training curriculum, the ASAP identified a tailored subset of Level 1 coursework that would be applicable to the intent of the Panel's recommendation.

The below set of courses represent five hours of study that will orient the workforce to the tenets of SMA, the role SMA plays in assuring mission success, and the consequences of mission failure. This set of courses will be required for all new NASA civil servants.

- NASA Safety and Mission Assurance Overview—1 hour
- Introduction to Technical Authority—1 hour
- Risk Leadership—1.5 hours
- Overview of Mishap Investigation—1.5 hours

In addition, new civil servants that support programs and projects will have an additional five and a half hours of course work required to include:

- Hazard Analysis Basics—1 hour
- NASA Human Factors in Mishap Investigations for Programs and Projects—1.25 hours
- Introduction to Root Cause Analysis—1.5 hours
- Probabilistic Risk Assessment Overview—0.75 hours
- Risk Management Overview—1 hour

The NASA Safety Center and the Office of the Chief Human Capital Officer have been working together to implement this training starting in August 2020. Additionally, each year in conjunction with the Day of Remembrance, NASA is requiring that all NASA civil servants complete a mandatory "lessons learned" course. This year, the Apollo 1 Case Study was assigned to every civil servant. A new case study will be selected annually.

NASA will continue to work to find the optimal balance between requiring training and advancing a robust safety culture.

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 (AIAA) 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 (SAIC)
- Former Chair, G-48 System Safety Committee 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 the 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 actively led or supported standards-developing activities for system safety and other specialty engineering disciplines. From 2010 to 2019, Mr. West 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 to 2013 and was the Board's Treasurer from 2012 to 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 earned 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 he is a registered Professional Engineer (PE). Mr. West enjoys astronomy, triathlons, and traveling.

Dr. 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 U.S. Air Force (USAF) 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, as well as 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, the Senior Executive Service Presidential Rank Award, the W. Randolph Lovelace Award, the 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 leader of 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 she served aboard the ISS 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.

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 Lieutenant 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 as 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 he 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 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, and Fleet Evaluation Pilot; he was also a squadron Aviation Safety Officer. Captain Saindon served as 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, as well as 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, AstroPlanetview, LLC
- Former Deputy Director-Engineering in the Office of the Undersecretary for Research and Engineering, Department of Defense (DOD)
- Former Executive Director of the American Institute of Aeronautics and Astronautics (AIAA)
- Former NASA Astronaut

Dr. Sandra H. "Sandy" Magnus is Principal at AstroPlanetview, LLC, and the former Deputy Director for Engineering in the Office of the Undersecretary for Research and Engineering in the DOD. Before joining the DOD, she served as the Executive Director of the AIAA, the world's largest technical society dedicated to the global aerospace profession.

Born and raised in Belleville, IL, 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, the Office of the Secretary of Defense Medal for Exceptional Public Service, and the 40 at 40 Award (given to former collegiate women athletes to recognize the impact of Title IX).

Mr. Paul Sean Hill

- Independent Consultant, Author, Speaker, and Principal of Atlas Executive, LLC
- Former Director of Mission Operations, NASA Johnson Space Center
- Former Shuttle and ISS Flight Director

Paul Sean Hill is an author and speaker focused on the leadership principles that are critical in creating and leading high-performing teams in any industry. During his 25 years at NASA, Paul first developed Space Station construction techniques and then led flights from Mission Control as a Space Shuttle and International Space Station Flight Director. He supported 24 missions as a Flight Director from 1996 through 2005, culminating as the Lead Shuttle Flight Director for the return to flight on STS-114 after the Columbia accident.

After a series of senior leadership positions, Paul served as the Director of Mission Operations for human space flight from 2007 through 2014, responsible for all aspects of mission planning, flight controller and astronaut training, and Mission Control. He is credited with revolutionizing the leadership culture, dramatically reducing costs, and increasing capability, all while still conducting missions in space.

Before his work with NASA, Paul served in the U.S. Air Force in military satellite operations. He earned his Bachelor's and Master of Science degrees in aerospace engineering from Texas A&M University in 1984 and 1985, respectively, and was a member of the Corps of Cadets.

His professional awards include the Presidential Rank Award of Meritorious Executive, two NASA Outstanding Leadership Medals, the NASA Distinguished Service Medal, the NASA Exceptional Service Medal, the Rotary National Award for Space Achievement—Stellar Award, and selection as one of the Marshall Goldsmith 100 Coaches.

Rear Admiral Christopher Murray, USN (Ret.)

- Independent Consultant, Ground Truth Consulting, LLC
- Former Commander of the Naval Safety Center
- Former Assistant Chief of Staff, Operations (J3), JFC Naples, Italy
- Former Commander of Carrier Air Wing Nine
- Former Commander of Fighter Squadron One Forty Three
- Navy Fighter Weapons School Graduate

Rear Admiral Murray is currently an independent consultant providing defense marketing, business strategy, safety, risk management, and subject matter expert consulting services to the private corporations, the defense sector, and prominent law firms. He retired in July 2017 after more than 33 years of Naval Service. Immediately prior to retiring from active duty, Rear Admiral Murray served as the Commander of the Naval Safety Center from October 2014 to July 2017.

Rear Admiral Christopher Murray is a native of Springfield, VA. He graduated from James Madison University with a B.S. degree in business administration in 1980 and an M.S. in business administration in 1982. He was commissioned after completion of Aviation Officer Candidate School in October 1984, designated a naval flight officer at Naval Air Station Pensacola, FL, in December 1985, and completed training in the F-14A at Fighter Squadron (VF) 124 in October 1986.

At sea, Murray served in several F-14 VF squadrons, including tours with the Wolfpack of VF-1, the Gunfighters of VF-124 as an instructor, the Sundowners of VF-111 as Training Officer, and as a Department Head with the Tophatters of VF-14.

Operational command tours include Executive officer and subsequently the Commanding officer of VF-143 from October 2001 to July 2004 and Deputy Commander and subsequently Commander of Carrier Air Wing 9 from November 2006 to December 2009.

Ashore, Murray served at Naval Air Systems Command as the Deputy Program Manager, Systems Engineering, for the F-14 Program Office (PMA-241). He completed his joint tour on the staff of United States Pacific Command, where he served as the Current Air Operations Officer (J311). He also served as Executive Assistant to the Commander, Naval Air Force, U.S. Atlantic Fleet, from August 2004 to August 2006. He attended the Royal College of Defense Studies in London from January 2010 to August 2010. Murray served as section head for Strike Aircraft plans and requirements (N98S) on the Chief of Naval Operations' staff from August 2010 to February 2013. His subsequent tour was on the staff of the Secretary of Defense in the Air Warfare Division of the Director, Operational Test and Evaluation.

Murray's first flag tour was as the Assistant Chief of Staff for Operations (J3) at JFC Naples from June 2013 to September 2014. He assumed command of Naval Safety Center on October 9, 2014, and departed upon retirement on June 2, 2017.

His awards include the Navy Distinguished Service Medal, the Defense Superior Service Medal, the Legion of Merit, the Defense Meritorious Service Medal, the Meritorious Service Medal, the Air Medal, the Navy and Marine Corps Commendation Medal, the Navy and Marine Corps Achievement Medal, seven Battle Efficiency awards, and various other personal achievement and service awards. He considers those awards earned throughout his career associated with unit performance to be most satisfying and representative of Naval Service.

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, serving 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. Lisa Hackley, ASAP Administrative Officer

Ms. Lisa Hackley has worked at NASA Headquarters for over 29 years providing administrative support for numerous mission directorates and divisions, including the Office of Space Flight (now Human Operations and Exploration), the Office of Life and Microgravity Science and Applications (now Space Life and Physical Sciences), the Office of Biological and Physical Research and the Office of International and Interagency Relations (OIIR). Prior to joining the Advisory Committee Management Division (ACMD) as the ASAP Administrative Officer in May 2019, Ms. Hackley worked in OIIR's Export Control and Interagency Liaison division for 15 years, including a voluntary secondment to the Federal Emergency Management Agency (FEMA) in late 2017 to assist with the hurricane relief efforts.

Ms. Kerry Leeman, ASAP Annual Report Editor

Ms. Kerry Leeman received B.A. degrees from the University of Houston in philosophy and technical writing. With over two decades of experience as a technical writing professional spanning the aviation, aerospace, petrochemical, and biomedical industries, she joined the ASAP as a technical report writer in 2019. Her prior experience with NASA includes technical writing and editing for the Constellation Space Suit Program and demonstrating the extravehicular mobility unit spacesuit to Houston-area students. She is currently a technical writing consultant for a regulatory and energy transmission services agency in Austin, TX.

APPENDIX D

NASA Aircraft Fleet Safety and Sustainment

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

August 31, 2020

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

Dear Mr. Bridenstine:

In accordance with your request, members of the Aerospace Safety Advisory Panel, led by Rear Admiral Christopher Murray USN (Ret), performed an assessment of the safety aspects related to NASA's operation and sustainability of its diverse and unique aircraft fleet. The report documenting the results of that assessment is attached.

Overall, we concluded that aviation safety is well managed by NASA. We do, however, provide some advice on areas where safety-related processes and the NASA organizational structure for aircraft safety could be improved. We also provide a recommendation for the safe long-term sustainment of the aircraft fleet.

We would be pleased to discuss our insights from this assessment with you in detail at your convenience.

Respectfully,

Patricia Sanders

Dr. Patricia Sanders
Chair, Aerospace Safety Advisory Panel

Enclosure

cc:
OIIR/Ms. Hamilton

NASA Aircraft Fleet Safety and Sustainment Assessment Report

Introduction

This assessment was undertaken at the request of the Administrator to inform future decisions on the operation and sustainability of NASA's aircraft fleet (Terms of Reference attached). The Aviation Safety Advisory Panel (ASAP) primary team consisted of Dr. Don McErlean, Mr. David West, Dr. Richard Williams, and Rear Admiral Chris Murray, USN (Ret.), but the final product was coordinated with the entire Panel. The assessment was conducted from May 14, 2020, to July 14, 2020, with multiple personnel interviewed (list attached), as well as Panel discussions.

ASAP observations and assessment

Overall, aviation safety is well managed at NASA. There are very positive trends in mishap rates, injuries, and reporting. NASA's Safety Management System and associated procedures are well delineated in NASA Procedural Requirement (NPR) 7900, Aircraft Operations Management, to include remediation measures for aircrew who are not meeting standards. The Intercenter Aircraft Operations Panel (IAOP), which is led by the Aircraft Management Division (AMD), is well received and performs the following functions: conducts audits of operational aviation entities on a three-year basis, has the capability to conduct audits and build remediation plans in response to incidents that have occurred, and provides a forum for the aviation community to share lessons learned and best practices. NASA is manned, trained, and equipped to operate their own aircraft. Commercial Air Services (CAS) have been used to some extent, but the NASA Centers are not optimally manned to support such efforts. Increasing CAS efforts in the future needs to be balanced by the risk incurred with not being manned accordingly to provide oversight. Aviation Safety training exists at NASA, but completion of that training is not a requirement for personnel who work in aviation entities.

NASA organizational processes to be considered for improvement

- The reporting of significant events up the chain of command has proven to be problematic. Significant events, whether they are related to aviation safety or not, are not being reported to the Administrator in a timely manner. There needs to be a process in place which bounds the reporting of what is significant, vice allowing personnel at all levels of the organization to make the decision on what is reported to the Administrator. Simply put, leadership at the highest levels needs to be prepared by their organization with the information they need to answer questions from the executive and legislative branches of government, along with the media.
- The ability to grant the "Concept of Privilege" to witnesses in mishap investigations would be of great utility to NASA. This is a time-honored practice in the Department of Defense where key witnesses are granted the concept of privilege by the senior member of the accident board so they will be truthful and help the accident board get to the root cause of the mishap, without fear of legal repercussions. A separate process exists for legal culpability, but it is not associated

with the mishap investigation. NASA has presented this proposal to Congress, but its deliberation is being held up while Congress deals with the pandemic.

- NASA has a wide range of reactive metrics that the AMD uses to characterize aviation safety performance. With the help of the NASA Safety Center and their data analysis capability, more proactive and predictive metrics could be introduced to prevent mishaps, fatalities, incidents, and injuries.

NASA organizational structure for aircraft safety is not optimized

- The AMD, the Headquarters entity responsible for Aviation Safety, is located under the Mission Support Directorate and is not represented as it should be in the NASA organizational structure. Due to this situation, funding for Aviation Safety, along with funding for Aviation, is not considered to be part of "core" work, and funding must be fought for on a yearly basis; this includes critical safety of flight systems like the NASA Aircraft Management Information System (NAMIS). If Aviation activities support the core work that NASA does, they need to be funded in that manner. The AMD does not have a "direct line" to either the Administrator or the Associate Administrator, which is a widely accepted High Risk Safety best practice. The Office of Safety and Mission Assurance (OSMA) is receptive to having Aviation Safety in their organization and would support the Aircraft Management Director having direct communication authority to the Administrator or the Associate Administrator. This initiative could also tie the AMD (Aviation Safety) with the Technical Authority for Safety (OSMA).
- The NASA Safety Center (NSC) could have a greater role in creating safety training for the aviation community; helping to create more proactive and predictive safety metrics.
- Regionalization of the NASA Centers should support teaming, mentorship, and the best use of assets; a Regional Lead/Follow concept should make the smaller Centers more whole and allow the bigger Centers to positively influence the region through leadership/mentorship.

Long-term planning for aircraft recapitalization lacks structure and rigor

- Aging aircraft is a concern on every flight line at NASA. The Center Directors or Science Mission Directors have been charged with leading efforts to update their aircraft when required, and a perfect example of this is Kennedy Space Center's recent recapitalization effort for their helicopters. Dynamic Center Directors have healthy organizations because they proactively work the requirement through the organization and receive approval for procurement of a suitable follow-on aircraft. This also holds true for unique aircraft (e.g., Super Guppy and the Stratospheric Observatory for Infrared Astronomy [SOFIA]) and the astronaut training aircraft, the T-38. The Astronaut Office presented a compelling argument for the requirement to train astronauts in a dynamic flight environment to be used as a training tool for decision-making in space, which is currently supported by T-38s. Since the U.S. Air Force still operates the T-38, the aircraft is being maintained satisfactorily. However, there will be a time when the

Air Force divests itself of the T-38, and proper maintenance and logistic support will become unachievable. The Astronaut Office needs to start working on a plan now to replace it. A process currently exists for fortifying and validating aircraft requirements, the Aircraft Advisory Panel, but it deals mainly with decision-making related to acquiring and retiring aircraft within a short-term timeframe. This Panel does not look across the entire NASA portfolio with priorities based on the long-term vision of the organization. A validated requirements process does not exist where a centralized entity validates aviation requirements with the Administrator's strategic vision and meets the needs of the aviation stakeholders.

- Personnel required to support and administer CAS are not funded or specifically trained to support the effort. The work-around is to engage personnel who support generic aircraft and are "dual-hatted" and have to time-share their efforts when CAS is utilized.

ASAP's recommendations

- **Move the AMD to the Safety and Mission Assurance Directorate and allow Aircraft Management to have a direct line to the Associate Administrator or the Administrator, when required.**
- **Aviation operations and safety need to be considered as core and funded accordingly.**
- **A formalized process to reporting significant events to the Administrator needs to be adopted.**
- **A group, chaired by the Associate Administrator, needs to be created that balances the organization's aircraft requirements against the Administrator's strategic plan. This group will also have responsibility for approving aircraft recapitalization plans.**
- **The AMD, NSC, and Aviation Office should collaborate on a yearly basis to review/expand the current reactive Aviation Safety metrics to include proactive and predictive ones.**
- **If NASA decides to expand the level of CAS operations, a manpower study needs to be conducted to determine the correct manpower levels that need to be in place to adequately support the initiative.**
- **Aviation Safety training should be required for all personnel who work in aviation entities.**
- **"Best practices" should be compiled and shared among the NASA Centers and Science Mission Directorates.**

AEROSPACE SAFETY ADVISORY PANEL

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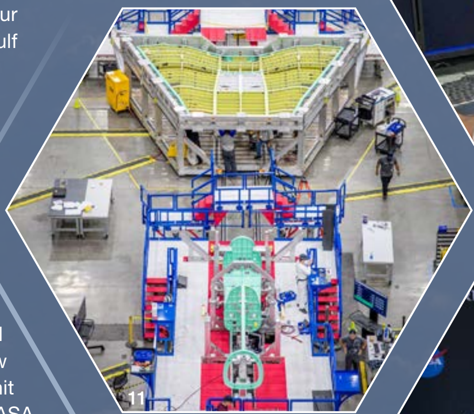

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ON THE COVER

Background: This view of Earth's horizon as the sun sets over the Pacific Ocean was taken by an Expedition 7 crewmember onboard the International Space Station (ISS) in July 2003. (NASA) **Front: 1.** The Space Launch System (SLS) rocket is shown installed on the B-2 Test Stand at NASA's Stennis Space Center (SSC). (NASA) **2.** After four months of rigorous testing in the space environments simulation facility at NASA's Plum Brook Station, the Orion spacecraft is certified. (NASA/Marvin Smith) **3.** NASA astronaut Bob Behnken gives a thumbs up during a spacewalk to install hardware and upgrade ISS systems on July 21, 2020. (NASA) **4.** Expedition 64 NASA astronaut Kate Rubins is seen as she and fellow crewmates prepare for their Soyuz launch on October 14, 2020. (NASA/GCTC/Andrey Shelepin) **5.** The SpaceX Crew Dragon approaches the ISS. (NASA) **6.** The first SLS rocket stage is guided toward NASA's Pegasus barge on January 8, 2020 ahead of its forthcoming journey to SSC for the core stage Green Run test series. (NASA) **7.** NASA astronauts Douglas Hurley (left) and Robert Behnken (right) participate in a dress rehearsal for launch at Kennedy Space Center (KSC) in Florida on May 23, 2020, ahead of NASA's SpaceX Demo-2 mission to the ISS. (NASA/Kim Shiflett) **Back: 8.** The Boeing CST-100 Starliner spacecraft is guided into position above a United Launch Alliance Atlas V rocket at the Vertical Integration Facility at Space Launch Complex 41 at Florida's Cape Canaveral Air Force Station on November 21, 2019. (NASA/Cory Huston) **9.** The SpaceX Crew Dragon Endeavour spacecraft is seen as it lands in the Gulf of Mexico off the coast of Pensacola, Florida, August 2, 2020. (NASA/Bill Ingalls) **10.** Inside the Launch Control Center's Firing Room 1 at KSC, members of the Artemis I launch team rehearse the procedures for fueling the SLS rocket on August 18, 2020. (NASA/Chad Siwik) **11.** The X-59 Quiet SuperSonic Technology (QueSST) aircraft main assembly coming together. (Lockheed Martin) **12.** A prototype of NASA's new Exploration Extravehicular Mobility Unit (xEMU) is seen October 15, 2019 at NASA Headquarters. (NASA/Joel Kowsky)

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