National Aeronautics and
Space Administration

Aerospace Safety Advisory Panel

Annual Report

2022

NASA Aerospace Safety Advisory Panel
National Aeronautics and Space Administration
Washington, DC 20546

January 23, 2023

The Honorable Bill Nelson
Administrator
National Aeronautics and Space Administration
Washington, DC 20546

Dear Sen. Nelson:

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 2022 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 2022 fact-finding and quarterly public meetings; direct observations of NASA operations and decision-making; discussions with NASA management, employees, and contractors; and the Panel members' past experiences.

The Panel believes that how NASA manages human space flight programs has a significant impact on the risks associated with them. We believe that NASA's vision for the future, and a clear definition of how it will evaluate and make risk decisions, are extremely important factors in managing human space flight safety. A focus of this report is three formal recommendations made in 2021 and where we have observed major progress. We also recognize that these require long-term efforts and we highlight remaining challenges. In particular, the management structure for the Artemis campaigns has evolved to one that supports disciplined systems engineering and integration (SE&I). Maturing and implementing the SE&I processes, along with the next steps to further a strategic vision for human space exploration, should be a priority for NASA in the coming year.

In addition to observations on the status of the top strategic areas noted in 2021, we comment on an additional noteworthy risk area for Agency attention, namely the future of missions in Low-Earth Orbit (LEO). While lunar and deep space exploration grow in prominence, the key role played by operations in LEO toward understanding and managing exploration risk cannot be discounted. This report will outline challenges that must be deliberately addressed in that region. Updated assessments of some ongoing areas of the Panel's attention are also provided.

I submit the ASAP Annual Report for 2022 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

January 23, 2023

The Honorable Kamala Harris
President of the Senate
Washington, DC 20510

Dear Madam President:

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Sincerely,

Patricia Sanders

Dr. Patricia Sanders
Chair, Aerospace Safety Advisory Panel

Enclosure

NASA Aerospace Safety Advisory Panel
National Aeronautics and Space Administration
Washington, DC 20546

January 23, 2023

The Honorable Kevin McCarthy
Speaker of the House of Representatives
Washington, DC 20510

Dear Mr. Speaker:

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Dr. Patricia Sanders
Chair, Aerospace Safety Advisory Panel

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Preface

The Aerospace Safety Advisory Panel (ASAP or Panel) 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 the Panel identified or raised during its activities over the past year. The full text of the recommendations submitted to the Administrator during 2022 is included as Appendix A, along with the Panel's open recommendations from prior years. Rationale for recommendations closed in 2022 is included as Appendix B. The Panel's issues, concerns, and recommendations are based upon the ASAP fact-finding and quarterly public meetings; insight visits and meetings; direct observations of NASA operations and decision-making; discussions with NASA management, employees, and contractors; and the Panel members' expertise.

I. Introduction and Overview

Throughout 2022, as a form of normalcy emerged from the pandemic, the Aerospace Safety Advisory Panel (ASAP or Panel) returned to in-person engagements and carried on a series of insight and fact-finding discussions, along with its quarterly meetings. The Panel placed an emphasis on the significant strategic-level recommendations that it made in 2021, while continuing to explore NASA's substantial ongoing program of work.

The Panel has observed major progress toward addressing the three key top-level recommendations it proffered in 2021. However, it recognizes that completely implementing the 2021 strategic recommendations requires long-term effort, and NASA has some remaining challenges to address. This report will discuss both the progress that NASA has made during 2022 as well as the remaining challenges.

Two of the ASAP's 2021 strategic recommendations addressed several steps the Panel believed the Agency needed to take to effectively manage integrated risks while developing and executing a historically challenging exploration campaign. These recommendations included, but were not limited to, developing a strategic vision; managing the workforce for the evolving space exploration environment; establishing flexible and responsive acquisition strategies; communicating intentions internally and externally; and managing Artemis as an integrated program. The third recommendation presents the Panel's proposal for NASA governance cohesion across the Agency to focus on unity in the workforce to achieve the Agency's goals.

Many of the Panel's comments in the original recommendations, as well as observations regarding NASA's progress to fulfilling the recommendations, relate to the steps discussed above; in short, entail the "what" that the Panel sees as important concrete actions that need addressing. In contrast, the Agency Governance subsection focuses on the "how," discussing Panel recommendations on Agency leadership internal engagements that serve to provide transparency and facilitate risk management. How NASA manages human space flight programs and its specific management choices have a significant impact on the risks associated with those programs. Clear identification of responsibility and accountability for safety and risk management that is well understood throughout the Agency and its stakeholders is critical.

Following a discussion of the status of the three 2021 strategic recommendations in Section II, the report continues in Section III with an emphasis on the "why," stressing the importance of implementing the recommendations to manage safety and risk attitudes deeply embedded in the Agency's workforce and safety culture.

In addition to observations on the status of the top strategic areas previously put forward, the Panel's work this year established an additional noteworthy risk area for Agency attention, namely the future of missions in Low-Earth Orbit (LEO). While lunar and deep space exploration grow in prominence, the key role played by LEO operations toward understanding and managing exploration risk cannot be discounted. This report will, therefore, talk to the challenges that must continue to be deliberately addressed in LEO. Updated assessments of some ongoing areas of interest will also be provided.

Finally, in 2022, at the request of NASA leadership, the ASAP looked at the safety aspects of the resumption of X-plane flight tests—an activity that NASA has excelled at in the past but has not engaged in during recent years. The Panel's report on that brief investigation is included as an annex to this year's report.

II. Continued Focus on Strategic Recommendations

A. Strategic Progress

For the last several years and very explicitly in the ASAP Annual Report for 2021, the Panel has emphasized the value of articulating an overarching strategic vision, leadership philosophy, and set of guiding principles that will chart a path for the Agency and its role in the future of space exploration. In addition, the Agency's priorities and processes should be clearly defined and communicated. The Panel believes this is extremely critical for NASA to best manage acquisition, safety, and technical risks as well as to inform future investment priorities for the Agency and its programs. Establishing a clear and broadly disseminated organizational strategy, aligned organizational structure, guiding principles, supporting processes, and priorities is essential for ensuring the workforce has a clear understanding of the lines of authority, accountability, and responsibility, and for promoting effective decision-making, risk management, and resource utilization aligned with Agency priorities.

Recommendation 2021-05-01

NASA should develop a strategic vision for the future of space explanation and operations that encompasses at least the next twenty years, including potential alternative scenarios, that is driven by how the Agency is going to understand and manage risk in the more complex environment in which it will be operating.

- The vision should describe the role that NASA intends to play during that period and how it plans to engage with both commercial and international partners.
- NASA should assess the workforce, including the number, types, skills, experience, and responsibilities that will be required, and infrastructure facility requirements, with a plan for managing changes needed to meet those requirements.
- NASA should also propose general criteria for evaluating "make, manage, or buy" decisions on future program or projects.
- All aspects of the strategic vision and its implementation should be clearly ad unambiguously communicated throughout the Agency.

In the ASAP Annual Report for 2021, as denoted below, the Panel provided the recommendation for the Agency "…to develop a strategic vision for the future of space exploration and operations…." The Panel recognized that this is a challenging undertaking and did not expect quick completion—it will take time to effectively implement this recommendation across the Agency.

In the past year the NASA leadership team, recognizing the value of the recommendation, has invested a considerable amount of their time and Agency resources to develop the underpinnings of such a strategy. And, in the spirit of transparency, they have been proactive in communicating their vision, strategic priorities, and overall goals to the extended NASA leaders at headquarters and the Centers, the NASA workforce, external customers, and stakeholders. The Agency has also solicited for feedback from both internal and external communities to ensure the resulting strategy is sound, well-understood, and poised for broad community alignment and effective implementation. As a consequence, the Agency's efforts have culminated in the publication of two Capstone documents: NASA Strategic Plan 2022 and its *Moon to Mars Objectives*.

The *NASA Strategic Plan 2022* focused on four themes—Discover, Explore, Innovate, and Advance—and established four strategic goals:

"The *2022 Strategic Plan* reflects NASA's constancy of purpose, while emphasizing the need for transparency, public engagement, and cooperation with industry, academia, international, and other partners"

— The Honorable Bill Nelson, NASA Administrator

- Expand human knowledge through new scientific discoveries.
- Extend human presence to the Moon and on toward Mars for sustainable, long-term exploration, development, and utilization.
- Catalyze economic growth and drive innovation to address national challenges.
- Enhance capabilities and operations to catalyze current and future mission success.

Within each of these goals, there are several notable strategic objectives outlined that will certainly set priorities and drive collaboration and innovation across the Agency and the NASA Centers.

NASA's organizational core values, displayed in Figure 1, are a key component of the strategy. As noted below, safety is identified as a cornerstone core value. Other core values are mentioned, but safety is the critical core value that must be communicated, discussed, and celebrated every day within the lifelines of the organization to establish a safety culture that can effectively execute and manage the day-to-day technical risks associated with NASA's challenging and complex mission set. A safety culture creates the behaviors necessary for an organization to be effective and to enable it to discuss—and resolve or mitigate—difficult issues and risks up, down, and across the chain of command on a daily basis. The Panel will revisit safety culture and its core attributes later in this report.

NASA's existing Core Values of Safety, Integrity, Inclusion, Teamwork, and Excellence mandate individual and organizational behavior across the Agency at all levels:

- **Safety**
  NASA's constant attention to safety is the cornerstone upon which we build mission success.
- **Inclusion**
  NASA is committed to a culture of diversity, inclusion, and equity, where all employees feel welcome, respected, and engaged.
- **Integrity**
  NASA is committed to maintaining an environment of trust, built upon honesty, ethical behavior, respect, and candor.
- **Teamwork**
  NASA's most powerful asset for achieving mission success is a multi-disciplinary team of diverse, talented people across all NASA Centers.
- **Excellence**
  To achieve the highest standards in engineering, research, operations, and management in support of mission success, NASA is committed to nurturing an organizational culture in which individuals make full use of their time, talent, and opportunities to pursue excellence in conducting all Agency efforts.

Figure 1.
NASA's core values (reference: NASA Strategic Plan 2022).

The *Moon to Mars Objectives* document clearly articulated the important priorities to accomplish a Moon-to-Mars mission—and coupled with the ongoing long-term mission architecture definition work—sets NASA on course to identify the technical challenges and safety risks associated with its exploration endeavors as well as where best to align resources across the Agency to be successful. As noted earlier, the Panel views the NASA Strategic Plan 2022 and the Moon to Mars Objectives as capstone documents that are moving the Agency on the right vector to operationalizing its strategy and priorities. The Agency has made significant progress in understanding and managing risk for the complex lunar campaign as it begins to articulate and communicate priorities and then translate them into tangible action plans.

> "These objectives provide the connective tissue between deep space human exploration destinations and the capabilities required to accomplish our goal at the Moon, Mars, and beyond."
>
> — Pam Melroy, Deputy Administrator, NASA

As the Deputy Administrator stated in the "Foreword" to the *Moon to Mars Objectives*, the document provides the essential "connective tissue" for NASA to embrace across the Agency to be successful in the ambitious exploration endeavor.

ASAP Recommendation 2021-05-01 has multiple facets, however, besides the identification of a strategic vision. The Panel reviewed the work NASA completed in 2022 related to the recommendation, and to move this recommendation to closure, the Panel recommends the following actions:

1. **Vision and strategy component**
   The *NASA Strategic Plan 2022* provides a broad set of Agency strategic goals and subsequent objectives. The *Moon-to-Mars Objectives* articulation and subsequent priorities are also very well done. Both documents provide a compelling and understandable set of objectives and priorities for the Agency and its Centers. In addition, both documents provide an initial definition of NASA's evolving role in the future of space exploration and how it will engage its internal workforce and external customers and contractors involved in the Moon-to-Mars mission, as well as set its strategic objectives and priorities to implement this complex mission set.

   NASA should continue to formulate and refine the subsequent goals and objectives into tangible and executable plans and supporting actions to fully operationalize the vision and strategy as well as to create the necessary shared accountability and responsibility necessary to achieve the desired outcomes and results while managing risk appropriately. The Panel looks forward to seeing this additional level of detail in 2023.

As noted earlier, the Panel also applauds NASA's proactive efforts to engage its external customers and the space industrial base on its strategic plan and priorities. Through this engagement, one important set of stakeholders to which NASA must attend is the Agency's international partners and other stakeholders. It is evident that NASA has included them in these strategic discussions and dialogue thus far. The Panel encourages the continued engagement with the international partners, particularly as the Agency adds details and specific action plans toward operationalizing this strategy. The international partners and stakeholders could provide meaningful value by not only identifying critical technical and safety risks associated with the strategy and plans, but also, more importantly, by providing significant contributions to mitigate these risks.

Finally, the Panel suggests the comprehensive, strategic approach to the *Moon to Mars Objectives* also be applied to NASA operations in LEO so that a set of unifying strategic objectives, priorities, and shared desired outcomes be defined and then aligned with an appropriate organizational structure to directly manage and mitigate acquisition, technical, and safety risks across all NASA LEO programs. An integrated LEO plan, combined with the work completed to date for the exploration campaign, would provide a more complete and comprehensive vision and strategy for the Agency across all its endeavors, leading to a global agency-wide methodology and operational execution plan. This will be further discussed in Section IV of this annual report.

2. **Workforce and infrastructure component**
   A motivated, educated, and talented workforce—and infrastructure aligned to the Agency's most consequential goals and objectives—is important to manage and mitigate risk to achieve desired outcomes. To date, the Panel has seen limited information that NASA Headquarters has taken steps to transmit its vision, strategy, priorities, and desired outcomes—particularly those relative to workforce and infrastructure—to the Centers. For example, during an insight visit to the Marshall Space Flight Center in September, the Panel received its first glimpse of a deliberate flow-down of the Agency's strategy to a Center's strategic priorities and decision space (specifically as it relates to the *NASA Strategic Plan 2022* and to the *Moon to Mars Objectives* document). The discussion provided the first indication of an explicit strategic coupling from NASA Headquarters to a NASA Center. However, it is not clear how the Marshall Space Flight Center is operationalizing the information and how Center priorities and workforce will produce the desired outcomes. As a follow-on in 2023, the Panel looks forward to seeing similar strategic linkages to all Centers, along with the specific executable plans and actions for success. The ASAP's Recommendation 2021-05-02—for NASA to lead change throughout the Agency using a "board of directors"-like approach—provides a tool that can be used as the leadership and decision-making forum to ensure the Agency's strategy is consistently implemented across the NASA Centers. (The "Agency Governance" subsection provides further discussion of this concern).

3. **Acquisition and contracting component**
   The Panel believes the Agency has begun to mature its efforts in acquisition management to address

the need for strategic decision-making when faced with "make, manage, or buy" acquisition options. Furthermore, the Agency has also created the right vector and actions to operationalize its approach. In August 2021, the NASA Deputy Administrator assembled an acquisition tiger team to begin assessing acquisition and past contracting challenges, to establish Agency priorities and goals, to put effective processes and organizational structures in place, and to utilize supporting metrics to monitor progress against these priorities and goals. These efforts are critical, as NASA's choices regarding acquisition approaches, contract types, and contracting relationships and responsibilities have direct implications relative to risk management, acceptance, and mitigation. The Panel is encouraged by recent NASA acquisition initiatives that not only meet near-term requirements but also address future needs while remaining thoughtful about the current and future state of the space industrial base. As an example, the Panel applauds NASA's efforts in 2022 to craft the acquisition strategy of the Exploration Extravehicular Mobility Unit (xEMU). NASA's strategy encompasses:

- A long-term view for the xEMU.
- A creative contract structure that enables flexibility for the Agency to refine its requirements and needs as the mission architecture evolves.
- An ability to balance and mitigate risk over the life of the contract.
- A broad engagement of the space industrial base with flexibility to expand if warranted.
- A structure to incentivize innovation and provide cost-management tools to steward the taxpayers' dollars most effectively.

The xEMU acquisition strategy is a direct result of the renewed focus and changes NASA has made based on recommendations of the acquisition strategy tiger team. The Panel urges NASA to continue to review each program and associated acquisition strategy and goals with a holistic and long-term view from the start, and to apply the appropriate acquisition approach and process improvements to meet each program's desired outcome.

Coherent and understandable communication to the NASA workforce of the guiding intent that underpins each acquisition strategy and contracting approach, as well as the definition of responsibilities and authorities between NASA and industry, will help promulgate programmatic and technical risk management principles consistently throughout the Agency and, most importantly, begin to institutionalize them for the Artemis era and beyond. As the acquisition tiger team continues its program of work, the Panel will be interested in how NASA will define criteria and communicate rationale for Agency strategy driving "make, manage, or buy" acquisition approaches.

Finally, given the number of complex and diverse acquisitions ongoing and for NASA's foreseeable future, the Panel believes having strong acquisition experience in the NASA executive leadership team is critical. To ensure continued acquisition rigor, consistency, and discipline for the long term, the Panel encourages NASA and Congress to consider requiring acquisition experience for the Senate-confirmed appointee that will be assigned the Chief Acquisition Officer role.

4. **Workforce communications component**
   The Panel is very satisfied with the actions the Agency has taken to communicate the contents of the *NASA Strategic Plan 2022* and *Moon to Mars Objectives* internally to its workforce and externally to stakeholders. The Panel urges the Agency to continue to proactively inform and engage the workforce, its partners, customers, and supporting contractors as it operationalizes this vision, strategy, and objectives and creates executable plans. Communicating leadership's intent, core values, and priorities, eliciting and incorporating comments and feedback, and holding leaders at all levels accountable for the actions associated with this plan will bolster safe and effective outcomes.

   In summary, NASA has made great strides in 2022 to meet the intent of Recommendation 2021-05-01, which will better position the Agency for mindful risk management going forward. The Panel looks forward to NASA's continued progress in 2023 to fulfill the remaining open aspects of this recommendation as the Agency operationalizes and further implements its strategy.

B. Artemis Program Management

In the *ASAP Annual Report for 2021*, the following were areas of concern regarding program management across the NASA enterprise:

- There is no top-level Artemis program—and therefore no Artemis Program Manager—to provide comprehensive and aligned integrated guidance that directs resources of all Artemis programs and projects in a cohesive manner to manage the overall risk.
- There is no Artemis (campaign) prime integrating contractor, nor clarity on how important risk management functions are being accomplished in its absence.
- An unprecedented mix of acquisition approaches with asynchronous delivery time horizons presents risk management challenges.
- Regardless of whether a partner-approach or an acquisition-approach is used, consistent expectations of transparency and data-driven risk discussions are required.

Due to the risk implications inherent with the concerns noted above, the Panel issued the following recommendation:

Recommendation 2021-05-03
NASA should manage Artemis as an integrated program with top-down alignment, and designate a Program Manager endowed with authority, responsibility, and accountability, along with a robust bottom-up, collaborative feedback process for both Systems Engineering and Integration (SE&I) and risk management.

The Artemis campaign involves multiple elements acquired asynchronously with varying acquisition approaches across a timespan of a decade or more. Managing and understanding integrated risk across such a complex endeavor is challenging and requires a leader with the authority, responsibility, and accountability to ensure that NASA executes the missions as safely as possible.

NASA has made impressive strides in program management over the last year, both organizationally and technically to address some of the Panel's concerns:

1. **Artemis I mission**
   The historic launch and landing of Artemis I is a clear success. The mission was a tremendous milestone for NASA and represents years of focus and preparation by the overall NASA and supporting contractor workforce. The Panel congratulates NASA on achieving what is clearly a massive undertaking: the building and successful "first flight" of the Space Launch System (SLS), the Orion, and the supporting ground systems.

2. **Improvement of organizational effectiveness**
   NASA has taken notable steps to restructure their organizational approach to the Artemis campaign to better align with the Panel's recommendation. Of note, NASA has created the Exploration Systems Development Mission Directorate (ESDMD) to align focus, responsibility, and authority over all aspects of the Artemis campaign through the design and manufacturing phases. Although NASA has not yet formally created an Artemis Program Office with a senior Program Manager, NASA has spent significant effort to identify the necessary functions of managing integrated risks and has begun to address the overly complex organizational structures across the Agency. In particular, the ESDMD team has accomplished some remarkable thought and work on the subject, and matured processes that provide clarity during the development process. A good deal of work has also been accomplished to identify top-level requirements and assign them across the multiple elements of the architecture. The Panel applauds the emerging structure, processes, and guidance being defined for integrated risk management during the development phase.

3. **Improved architecture-to-design management**
   The Panel is very satisfied with the continued progress in managing the tight coupling between the Artemis mission architecture development and definition and the Artemis Systems Engineering and Integration (SE&I) functions to support a long-term integrated engineering plan for the Artemis campaign. The maturation and advancement of the architecture and SE&I processes, delivered artifacts, and the programmatic integration from the mission-level to program elements continues to be impressive; the Panel views this as critically important for the management and resolution of technical and safety risks. Top-level requirements, developed via architecture definition, better define the overall design trade space, and align the necessary science and technology investments. The Panel is pleased to see that an initial architecture review is planned for the first quarter of calendar year 2023 and will be followed by recurring annual reviews supported by focused analytical studies

and assessments. The recurring cycle of architecture reviews is important to enable evolution of the architecture and to maintain architecture configuration management across the Agency. There is no doubt that these efforts will provide the necessary design guideposts for the Moon-to-Mars mission set.

4. **Improved SE&I processes**

NASA continues to mature the development of important SE&I processes that clearly define engineering roles and responsibilities, enable design and development decisions, ensure program element integration, maintain engineering activity alignment, and most importantly, manage technical and safety risk. Key examples include:

- ***The maturation of the Artemis Integrated Product List.*** A comprehensive list has been created of all engineering artifacts in progress or baselined. Key systems engineering documents include the Risk Management Plan, the Systems Engineering Management Plan, the Schedule Management Plan, the Safety and Mission Assurance Plan, and the Configuration and Data Management Plan. These are all important foundational documents that describe key processes and establish clear lines of authority for engineering decision-making and risk acceptance/resolution.
- ***Requirements traceability.*** There is now improved traceability of requirements from the mission architecture, via the Human Rating Certification Requirements and Interoperability Standards Requirements documentation, to the SE&I requirements activities, including system element design and test. As intended, a clearly defined requirements traceability should deliver a well-integrated system designed to manage technical and safety risks as the program progresses. It also enables a bottom-up feedback loop to the architecture to understand emerging technical risks and trades, and to further inform evolution of the architecture at the mission level.
- ***Configuration control.*** Processes are now in place to maintain engineering baseline configuration at all levels, and they are interconnected. Continued focus on the interface requirements documents will be important for integration and interoperability going forward. To further enable efficient management of the integrated engineering baseline and ensure interoperability, the Agency is implementing a model-based systems engineering approach to create a single source of truth for the system design.
- ***Artemis master schedule.*** The output of the master schedule tool, reviewed monthly, informs leadership and the team of critical paths, remaining schedule margin, performance trends, emerging issues, cross-program dependencies, and change impacts to current and subsequent missions. The monthly reviews also ensure Artemis campaign alignment with all stakeholders, and they enable quick identification of any program disconnects or changes that could create technical risk.

Overall, the progress and improvements that NASA has made over the past two years to create an integrated Artemis campaign have been impressive and timely. Taken all together, the NASA leadership and workforce have matured the tools, processes, and products to manage, understand, and resolve technical and safety risks throughout the design process.

However, given that the Artemis campaign will be a multi-mission, ever-expanding endeavor over several decades, notable challenges remain. As described in the *ASAP Annual Report for 2021*, the Panel has the following lingering concerns:

5. **Ongoing Challenge: Split authorities between "development" and "operations."** While the establishment of ESDMD has brought some much-needed focus to the task of aligning multiple Artemis-related developments, the Panel remains very concerned about the overall approach NASA has adopted, which splits the development and operational functions of the Artemis campaign by assigning them to two parallel organizations, ESDMD and Space Operations Mission Directorate (SOMD). In NASA's organizational descriptions, a program is deemed operational when oversight is transitioned from the ESDMD to the SOMD for mission execution. Given that the Artemis campaign is a continuous iteration of test missions (akin to the Apollo missions) with objectives that require critical acquisitions at every mission milestone, and has an evolving end state, the application of the term "operational" is imprecise and can have serious risk management implications. Some of the Panel's more specific questions include:

    - How is NASA planning the transition of programs and projects from ESDMD to SOMD oversight, and what are the criteria that define a distinction between "developmental" and "operational"?
    - How are integrated risks—spread across multiple program/project elements and two parallel organizations—managed and tracked in a manner that is transparent to both directorates?
    - How are developmental issues that impact operations, and operational issues that impact developments, addressed in a manner that assures a program authority can efficiently direct resources and solutions between the two directorates?
    - For risks that touch both development and operations, who is the final authority for risk management accountability?

    The following case study, taken from the Artemis I launch processing, illustrates an example of where NASA has already experienced the impact that engineering decisions can have on operational risk management. Similar situations will certainly develop without clarity around the questions outlined above. The Panel urges NASA to act quickly to address the issue of integrated technical and operational risk management and safety, given the current organizational approach.

6. **Ongoing Challenge: Risk management in the absence of a prime integrating contractor.** As mentioned in the ASAP Annual Report for 2021, NASA has historically relied on a prime integrating

contractor to manage SE&I across subprograms and projects to ensure there is a consistency of standards, practices, and developmental outcomes across the program enterprise. In the context of "make, manage, or buy" acquisition rationale, the Panel would like to learn more in the coming year about how NASA's current approach—which involves a disparate collection of integrating contractors across multiple NASA Centers, programs, and projects—attains the same historic level of integration and results for successful risk management, without duplication of effort, or even conflicting outcomes.

Clean Pad Concept: A Case Study of Integrated Risk Management

Early in the development of the Artemis campaign, the Exploration Ground System (EGS) program decided to proceed with a "clean pad" concept for Space Launch Complex (SLC)-39B, the launch pad designated for the SLS. The intent of that decision was to achieve development cost savings for the EGS program and infrastructure simplicity to entice additional SLC-39B commercial users. However, the decision also led to significant restrictions on the ability to access and maintain the Orion and SLS rocket while at the launch pad. Simultaneously the SLS program designed the rocket with a limitation on the number of rollbacks that the rocket could withstand. The impact of these two decisions—made independently of an integrated Artemis program strategy that spanned design, development, manufacturing, and operations—manifested during the lead up to the Artemis I launch and drove unforeseen risk management considerations. As NASA progressed through major tests, rehearsals, and launch counts leading up to the first Artemis launch, the lack of robust, SLS-specific infrastructure at SLC-39B placed NASA in a position to consider and execute unplanned rollbacks to the Vehicle Assembly Building for essential maintenance and testing as issues arose during the launch flow as well as to avoid severe weather. The decision to perform an unscheduled rollback is highly impactful because the SLS, the Orion, and ground transporter infrastructure are exposed to additional technical risks throughout the rollback process, which also generates increased stress on the workforce, and is constrained by formal certification to no more than seven rolls in either direction. Rollbacks can disrupt complex workflows and notably increase schedule pressures, possibly to the detriment of risk management options. Consequently, as NASA progressed through the wet-dress rehearsals and launch counts of Artemis I without all the on-pad infrastructure that would have been typical of previous NASA launch systems, the Agency had to balance hardware risks and schedule limitations related to rollbacks—a situation that increased the chance of accepting additional mission-related risk through technical and operational waivers in lieu of rolling back. In summary, NASA's current launch flow risk posture for the largest and most complex rocket system of the last several decades has been heavily shaped and strongly influenced by an early decision by the EGS program, absent an integrated Artemis strategy, to execute the "clean pad" concept, seemingly without due consideration for the inherent complexities of the SLS/Orion design, the learning curve of operating a launch flow for a wholly new rocket, and the challenges of rollbacks on risk management and schedule disruption. While this is now a case study based on 20/20 hindsight, the factors behind the outcomes—a lack of integrated decision-making by a top-level program manager who has the authority and accountability to understand and manage risk across all phases of the entire campaign—persist.

7. **Ongoing Challenge: Integration of a broad mix of acquisition approaches.** Scanning across the portfolio of projects that compose the Artemis campaign architecture, it is still unclear to the Panel in many cases how the individual elements of the Artemis mission sets come together based on the diverse and asynchronous contracting approaches and timelines. In the near-term, ensuring that all subsystem and individual project acquisition schedules and approaches are included on the previously mentioned Artemis integrated master schedule would better integrate the existing plans and acquisition integration points. Also, accelerating the institutionalization of the acquisition processes, procedures, and guiding principles emerging from the NASA acquisition tiger team efforts would further tightly couple these acquisition approaches.

8. **Ongoing Challenge: An irregular cadence.** The planned cadence of launches in the Artemis campaign is not conducive to creating an experienced workforce that is proficient at complex launch flows. For example, the break between launches for Artemis I and Artemis II is projected to be two years. To its credit, NASA is already taking steps to manage the expected turnover and loss of corporate knowledge in the workforce due to the gap between the two launches. However, even when a regular cadence of launches is established, only one per year is anticipated. As historical context, the Space Shuttle program—which executed multiple launches a year and was never considered "operational"—continually evolved both technical and operational parameters from mission-to-mission through the end of the program. Every Space Shuttle mission presented new risks that required active risk management. In every respect, each Artemis mission will be properly characterized as a test mission, as developmental elements critical to the lunar campaign (e.g., lunar lander, lunar transport, habitat, etc.) will be launched and integrated into the Artemis architecture. Every Artemis mission will be wholly unique for the foreseeable future.

C. Agency Governance

In the ASAP Annual Report for 2021, Section IV, Agency Governance, the Panel explored the links between executive expectations, governance approaches, leadership team performance, and risk management. As the section's title suggests, the emphasis was on governance, and the Panel intended its observations and recommendations to advance a broadly applicable governance style, rather than governance structure and/or membership. The Panel returns to this topic to emphasize the connection between how the Agency engages internally and its resulting success in setting and accomplishing strategic goals and overseeing an effective safety culture (as described in previous sections). There is a direct connection between governance style and assuring the Agency fosters an inherently effective safety culture that motivates the Panel to further explore this topic.

The summary text from the original recommendation is shown below:

Recommendation 2021-05-02
As a part of an overall risk management approach and in order to develop and execute its strategic vision for the future of space exploration, NASA should establish and provide leadership through a "board of directors" that includes the Center Directors and other key officials, with the emphasis on providing benefit to the Agency's mission as a cohesive whole, and not to the individual components of the Agency. The Board should act to identify the strategic risks and obstacles that NASA may encounter in executing its mission, evaluate Agency-level mitigation approaches, and align the efforts of all Centers to ensure desired outcomes.

The Panel is encouraged by the Agency's formal response in May 2022 in which NASA generally concurred with the thrust of the Panel's observations about governance (https://oiir.hq.nasa.gov/asap/documents/NASA_Response_to_ASAP_Recommend_Agency_Board_of_Directors_signed-5-5-2022.pdf). To clarify the Panel's focus on NASA governance—and the directly related internal engagement paradigm, transparent communications, and culture—and to move this recommendation to closure, the Panel describes more explicitly four critical dimensions to NASA's efforts to mature Agency governance:

1. Set strategy and make related, ongoing decisions as a "board" consisting of key Headquarters "program" *and* Center leadership.

   NASA's May 2022 response noted:

   > *Based on the recommendation, NASA will implement several specific improvements to ensure a strategic focus is maintained, that leaders continue to act as the "Board of Directors" in these existing meetings, and that the approach towards enterprise risks focuses on outcomes rather than tracking.*

   The Agency also responded that it "does not concur that a new board structure is required." The Panel agrees and considers the existing NASA management forum structure to be suited to setting strategy and managing programs, personnel, and risk. This component of the recommendation sets a goal to use that structure and include leaders from all affected Agency components—from programs to the Centers—in adjudicating all strategic decisions and risk acceptance.

2. Deliberately use the full and open forums to maximize transparency and engagement.

   In its May 2022 response, the Agency explained:

   > *NASA concurs with the intent of the recommendation to ensure that implementation of a strategic vision for space exploration is conducted as a cohesive whole, and not on individual components of*

the Agency, and with the intent that strategic risks and obstacles need to be identified, managed, and mitigated.

Again, the Panel agrees an effective "board" structure may very well be found in existing Agency-level management forums but believes Agency leadership must be more deliberate in setting an expectation for full and open forums to maximize transparency, engagement, and participation in formulation and execution. The board will be fully effective when all aspects of every decision are understood by the full team, and all affected leaders and organizational components are able and willing to participate in discussions and decisions.

The Panel's focus will remain on how NASA operationalizes day-to-day implementation of deliberate engagement and communication styles through which senior leaders adjudicate strategic direction and ongoing program performance, manage risk, and steward a culture of full transparency and engagement at and across all levels of management by example, starting at the top.

3. Deliberately align to Agency goals by employing the "board" to make smart (and often difficult) strategic resource choices across Centers—where the Agency's interests are what is explicitly considered and supported—which may require Center Directors to relinquish resources they would prefer to protect and preserve in the broader interest of the Agency's mission, goals, and budget.

   As NASA's May 2022 response describes:

   While wearing the "corporate hat" has long been an implicit expectation of participation in the Agency governance system, given long-term turnover in leadership, proactive steps can be taken to ensure this cultural norm is renewed. In order to renew expectations on "corporate hat" participation in Councils, NASA will:

   - *Have each Agency Governance Council Chair share this expectation at an in-board Council meeting that has broad attendance.*
   - *Ask each subordinate governance body Chair to also share the expectation.*
   - *Update the new Council member onboarding briefing and related materials on the "Resources for Members" section of the OneNASA corporate intranet site to communicate the expectation.*

   The ASAP recommendation emphasizes proactive discussion, evaluation of mitigations, and alignment of efforts. To support the ASAP's recommended emphasis, NASA will:

   - *Adjust the 2022 Baseline Performance Review reporting requirements on Enterprise Risk Management to focus on the performance of enterprise risk mitigation plans and discussion of their effectiveness, rather than on status and changes in rating.*
   - *Include in each Agency Governance Council charter specific chartered functions which allow for escalation to review (aligned) enterprise risks.*

The Panel applauds the Agency for sharing these more explicit expectations down through subordinate governance bodies. Also at the heart of the Panel's recommendation is the linkage of strategy with accountability and direct alignment of Agency-wide activities and resources with an Agency strategy. These often-difficult choices can lead parts of a larger organization to make decisions that look beneficial parochially at the expense of the "corporation" or, in this case, the Centers' rather than the Agency's best interest. The cultural emphasis on transparency, engagement, and participation, coupled with these explicit and aligning expectations, help counter that human tendency. Finally, the NASA leadership team, including the Center Directors, must be held accountable for performance in executing to the strategy.

4. Expect centers to then execute accordingly, bringing exceptions, new information, reclamas, et al. back to the "board."

   As the Panel has observed, transparency and engagement from the top-down are crucial. These approaches are equally important from the bottom-up. In the interest of broadly encouraging transparency, engagement, and alignment in strategy formulation and risk management, the ASAP proposes NASA modify the criteria for using the Agency Governance System as described in the Agency's May 2022 response to this recommendation. The italicized text below reflects the Panel's suggested modifications for issues and decisions that are coordinated through the Agency Governance System:

   - *High external stakeholder visibility.*
   - *A high degree of impact across organizations and Centers.*
   - *Significant long-term impact, requiring added diligence in decision-making.*
   - *Significant change to an existing mission strategy, risk acceptance, operating philosophy, or acquisition strategy.*

   Consistent with the previously described transparency and alignment, the Panel encourages NASA to err on the side of engaging the governance system liberally. Whether listening for weak signals or resisting organizational silence (discussed in the next section), and although seemingly trivial concerns may not warrant lengthy engagement from the leadership team, awareness of concerns and changes that appear minor to some may be found to have greater impact when assessed more broadly.

In summary, as a part of an overall risk management approach and to deliberately facilitate behaviors that combat organizational silence and enhance management effectiveness, the Panel recommends a "board of directors"-like senior leadership culture that includes the Center Directors and other key officials, with an emphasis on accountability to the Agency's mission as a cohesive whole, and not to the individual components of the Agency. The combined effect of these actions—and the deliberate implementation of the resulting behaviors—will improve alignment toward Agency objectives and strategy and encourage participation at

all levels by combatting organizational silence (as described in more detail in the following section). Boards and panels will be more apt to openly identify the strategic risks and obstacles that NASA may encounter in executing its mission, evaluate Agency-level mitigation approaches, and align the efforts of all centers to ensure desired outcomes.

The Panel's ongoing focus on governance style is driven both by recognition that, intentionally or not, senior leaders must simultaneously model behaviors they expect from their team and signal which behaviors will and will not be tolerated. Governance style, as described in this report, plays a critical role in deliberately sending those signals from the top-down and setting and/or reinforcing cultural norms at all levels that can strengthen or weaken team performance. In that vein, in 2023, the Panel will continue to engage with NASA on this topic as the Agency matures the approach proposed in its May 2022 response to the recommendation.

III. Pervasive Focus Areas

A. Safety Culture and Organizational Silence

An organization's "safety culture" is the system of shared values that guides choices about how to assess and respond to risk. The Columbia Accident Investigation Board (CAIB) identified a "broken safety culture" as one of the key organizational causes of the Columbia accident, noting "systemic flaws" that "erected barriers to effective communication." In its assessment, the CAIB reflected on the echoes of the Challenger accident, where, as the CAIB notes:

> *The organizational structure and hierarchy blocked effective communication of technical problems. Signals were overlooked, people were silenced, and useful information and dissenting views on technical issues did not surface at higher levels.*

In the wake of the Columbia accident, NASA took these assessments to heart, and made substantial, meaningful efforts to reform its organizational structure and culture to address these fundamental issues as it flew shuttles successfully through 2011. NASA leaders worked hard to signal openness to concerns and dissent and were overtly supportive of robust communications. To this day, there is evidence that NASA's awareness of the salience of safety culture to program and operational risk management persists. For example, the NASA Safety Center (a unit of the Office of Safety & Mission Assurance) recently offered a professional development program about "Organizational Silence," a collective phenomenon where employees feel compelled to silence, fail to speak up, or purposefully withhold their views out of fear that negative information will not be well-received by an organization's leaders.

Now, more than a decade hence, NASA must again rely on its safety culture and organization if they are to fly the Artemis missions safely. Training programs and simulation exercises notwithstanding, NASA has not had to exercise its risk communication "muscles" for launch operations over the intervening years since the Space Shuttle program's last flight when the lessons of Columbia were still fresh. The Panel is concerned

that NASA's concerted attention to a healthy safety culture may have diminished, leaving NASA vulnerable to the same flaws that contributed to previous failures. This concern was heightened by the circumstances surrounding NASA's decision to scrub the Artemis I launch in early September, as described in the following case example.

Artemis I Launch: A Case Study of Operational Risk

In early September 2022, NASA scrubbed the Artemis I launch as a result of the liquid hydrogen propellant leak after a Launch Control Center manual command error. A command error in a critical system is a serious condition that, in this case, could have put the vehicle and the launch pad at risk. The Panel has learned that this error was communicated in real time to the Launch Director, and then subsequently in internal and public forums, in a manner that was not up to the expectations set by the CAIB or by the recent "organizational silence" training program. This circumstance was an important—but missed—opportunity for NASA to model several crucial expectations that are foundational to a healthy safety culture, including the following:

- That anyone who makes a mistake is safe coming forward to immediately acknowledge having done so to facilitate a correction and risk management.
- That anyone who has risk-related information important to a decision must communicate that information with due urgency and can do so without fear of recrimination.
- That NASA will openly acknowledge errors and problems and explain the actions the Agency is taking to remedy them.
- That NASA will investigate the circumstances around errors in order to learn and improve.

Whether this case example represents one unique moment of mere inattentiveness or a deep and pervasive weakness, it serves to remind NASA of the critical need to attend closely to the fundamental tenets of a healthy safety culture: clear leadership commitment; continuous attention and education; open communications; transparency about mistakes; and engagement at all levels of the organization. There are certainly indicators of healthy roots in NASA's safety culture—for example, the Artemis I Flight Readiness Review in August 2022 was a robust meeting—but close attention to the foundational values that underpin robustness throughout the program is essential. In short, it is not enough to require the workforce to take a class in organizational silence. The Agency's leaders must model and support open communications and transparency every day, including encouraging decision-scrutiny and self-reporting of errors.

Specifically, the Panel strongly advises NASA to promote open discussion and listen closely to the concerns about the Artemis campaign, from risks inherent in the chosen management structure and acquisition approaches, to risks brought by the sheer scope, complexity, and content of the program, to design choices, to real-time operational risks. NASA must intentionally reinvigorate the culture of courage it began to build in the wake of Columbia's tragic loss. NASA's leaders must reward its employees for confronting mistakes openly, and they must explicitly model the right values by owning and discussing mistakes and investigating their root causes. They must support the instinct to challenge decisions that create risk. They must call a

halt to political finger-pointing borne of fear of attribution for weaknesses and errors. These values must be inculcated across the entire spectrum of development and execution.

These imperatives are even more urgent as NASA shifts to new, creative, and complex acquisition approaches that could have the unintended consequence of shifting the central cultural focus away from risk assessment and mitigation and attenuating robust risk communications as a variety of providers with varying cultures interact across developmental and operational contexts.

Ultimately, NASA must conduct its business every day in a way that reinforces psychological safety, that thwarts organizational silence, and that supports the ability of all to speak the truth as they understand it in an effort to operate safely. Adopting such a stance is a challenge for an organization that has faced a difficult resource environment and shifting political priorities, but it is crucial if NASA is to succeed and build resilience to risk and failure.

B. Workforce

The existence of a skilled and experienced workforce has always been critical for NASA to safely accomplish its mission. For several years, the Panel has commented on many issues related to the NASA workforce and the potential effects of workforce-related issues on safety and mission assurance. In the ASAP Annual Report for 2020, the Panel highlighted the importance of clearly communicating roles and responsibilities to the workforce in the face of NASA's evolving and increasingly complex missions and innovative acquisition strategies. In the first quarterly ASAP public meeting of 2021, the Panel reemphasized this challenge. In addition to effectively communicating with the workforce, NASA must be aware of, and proactively manage, various factors and situations affecting the size, composition, organization, and infrastructure to support the NASA workforce.

Of particular concern to the Panel is the potential for a significant reduction in the size and experience level of the workforce following the completion of the Artemis I mission. There have been reports that a sizable number of experienced workers may be retiring after Artemis I, impacting the resident knowledge base remaining to execute Artemis II.

In addition, several recent broad societal trends and phenomena may impact the dynamics and stability of NASA's workforce impacting its ability to execute. For example, forces that shape workers' views on their current positions, their outlook for the future, their geographic mobility, and the timeframe over which they may or may not be willing to stay in their current situation, have been permanently altered as society has navigated through the COVID-19 global pandemic.

A major change in employee expectations is the mode in which they work. As the pandemic began, employers across the country were forced to enable many, if not all, of their employees to work remotely. Now, nearly three years later, many employers have office facilities that are largely vacant, with most of their employees still working from home. This unprecedented availability of remote work has presented challenges to employers

in an already tight labor market. Many skilled workers may be reluctant to hire on with an employer that requires onsite work, when they can easily find employment with plenty of other employers that still enable them to work remotely. Many employers are experimenting with hybrid work environments, including NASA. However, different Centers are taking different approaches, making it difficult for the workforce to effectively communicate across the Agency. It would be beneficial for NASA to take an Agency-wide consistent approach to hybrid work requirements.

Finally, according to the U.S. Bureau of Labor Statistics, the rate of employees voluntarily leaving their jobs in the United States over the last year has reached new highs, a phenomenon commonly known as the "Great Resignation." There is also a related trend known as "quiet quitting," which has been described as millions of people not going "above and beyond" in their performance, but instead, just meeting the minimum requirements of their job description, affecting productivity and efficiency. Throughout its history, NASA's previous risk management successes have heavily leveraged an energized workforce with high morale, who often have gone "above and beyond" to catch process escapes and other risk issues. In fact, NASA has an entire recognition program for this cultural touchpoint for the workforce, the well-known "Silver Snoopy" space flight awareness award, which has notably acknowledged countless individuals who had a direct impact on flight safety through their heightened diligence. Given NASA's inherent reliance on the front-line workers to assure space flight safety practices, this "quiet quitting" phenomenon should be on NASA's risk management radar.

The larger societal trends, coupled with an aging workforce poised for retirement, reinforce the need for NASA to implement well-thought-out business continuity plans and a focus on continually building and maintaining a culture on safety and transparency. The Panel will remain attentive to how the Agency responds to these concerns and trends, particularly as they relate to risk management and safety.

IV. Additional Strategic Focus Area

The International Space Station and the Future of Low-Earth Orbit

NASA has made a lot of progress in strategically architecting, defining requirements, and developing robust and thorough SE&I processes to manage the complex system of systems and missions that comprise the lunar campaign. While the Agency has a firm focus and structure around its future endeavors in cis-lunar space, NASA is not planning to abandon operations in LEO. In fact, the vision for future operations in LEO is quite exciting. NASA is taking advantage of, and acting as a facilitator for, increasing engagement by private enterprise in space activities. The Agency is planning to transition from an owner/operator of an orbiting LEO space lab, the International Space Station (ISS), to being a customer for industry led LEO-based space stations. The shift parallels and is a progression of the commercial-led approach that the Agency has taken first for cargo deliveries to the ISS, and later for crew. Retiring the ISS, which at its end of life will have been on orbit for approximately 30 years and considerably beyond its original anticipated life, provides an opportunity for NASA to apply the "commercialization" paradigm to orbital laboratory services.

The NASA commercial cargo and crew programs have provided many lessons for both the Agency and industry on how to understand and manage risk, define accountability, and fine-tune certification processes to ensure safe operations. Indeed, new lessons continue to emerge as vehicle designs evolve and operations mature. As NASA takes the next step in maturing how it partners with industry to create a private orbiting laboratory capability, the Panel has several topics of import that will directly affect how risk is identified and managed.

ISS Life Extension

To allow for sufficient time to transition LEO science and technology development from the ISS to subsequent new U.S. commercial orbiting laboratories, NASA is proposing an ISS life extension from the previously announced date of 2024 to 2030. Due to the many interdependencies that are foundational to how the ISS was designed and operated, a safe and successful life extension can only happen with the full participation of all international partners. For example, the motion control, guidance, and other systems between the Russian segment and the U.S. segment are intrinsically intertwined. If all partners do not decide to extend to 2030 then the ISS program will need to understand and define what the shortcomings of a particular partner's withdrawal might be and identify if, and then how, that shortfall can be overcome.

As NASA continues to investigate ISS life extension, one critical item of concern to the Panel is the ISS deorbit plan. The Panel had a previous recommendation pertaining to ISS deorbit capability, which stated:

The Panel closed this recommendation in 2020 based on the fact that there was complete conceptual agreement on an approach across all of the partners, and a final agreement was described as imminent.

Recommendation 2012-01-02

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

Rationale: An unexpected, emergency event could precipitate the need to deorbit the ISS at any time. Timely development of the plan on how to respond to such a situation before it occurs will allow an optimum response and maximize the safety to the public in such a situation.

Subsequent detailed discussions among the ISS partners have identified technical and operational issues which need further addressing, so the Panel is returning to this topic. The urgency of defining a deorbit plan, first highlighted in 2012, has returned and is even more pressing given the expected and approaching end of service date. Discussions are ongoing between NASA and the Russian Space Agency to make the controlled deorbit plan more robust. The Panel is therefore reiterating its concern, first stated in 2012, about

the lack of a well-defined, fully funded controlled re-entry and deorbit plan for the ISS that is available on a timeline that supports the planned ISS retirement. Furthermore, the ISS partners are operating at risk, today, without the contingent plans and capability to deal with an emergency deorbit situation or an unsuccessful ISS partnership extension. The risk to public safety and space sustainability is increasing every year as the orbital altitudes in and around the ISS continue to become more densely populated by satellites, increasing the likelihood that an unplanned emergency ISS deorbit would also impact other resident space objects. Earlier studies on the risk posture and safety implications of an unplanned deorbit might require regular reviews given the rapidly changing nature of LEO activities.

Because of continued concerns, this year the Panel issued the following new recommendation at its October 2022 public meeting:

Recommendation 2022-05-01
NASA should define an executable and appropriately budgeted deorbit plan that includes implementation on a timeline to deliver a controlled re-entry capability to the ISS as soon as practicable to be in place for the need of a controlled deorbit in event of an emergency as well as in place before the retirement of the ISS, to ensure that the station is able to be de-orbited safely.

Another critical topic of interest related to the ISS life extension is the EMU. The Panel has been consistent in voicing concern about the age of the ISS EMU, the space suits, which have now been in use for nearly four decades, dating back to the early days of the Shuttle program. While the engineering teams have been vigilant in tracking anomalies and updating the hardware, the suits continue to manifest new problems. An ISS extension to 2030 means a critical and immediate requirement to continue to support external maintenance activities throughout that extension timeframe. The Panel believes that extravehicular activity (EVA) sustainability with current suits is a clear and present safety risk, and the on-orbit delivery of new ISS suits is imperative and must be executed as soon as possible. The Panel highlighted its concern in the following recommendation:

Recommendation 2019-02-01
NASA should begin an immediate transition to a next-generation Extra-Vehicular Activity (EVA) suit system EMU, before the risk to EVAS becomes unmanageable.

While the recommendation is still open, it is the Panel's understanding that NASA is in an acquisition process for new ISS suits, but until the Agency completes this effort, it is unclear what the targeted date for deployment on-orbit of new suits might be and whether the effort has adequate funding to achieve that goal. The Panel believes that to increase safety and to reduce risk, this needs to happen well before the end of life of the ISS.

Transition to Commercial LEO

The potential transition of NASA's LEO operations to a commercially owned and operated laboratory raises many fundamental strategic, technical, and operational questions that can directly impact how risk is managed. Addressing these questions provides both clarity for the workforce and frames the processes that need to be defined to manage risk mitigation and to optimize safety, both on behalf of NASA astronauts, but also for private citizens who might engage. Some of the strategic questions are the following:

- What are the U.S. Government's desired goals and objectives in LEO?
- Are NASA's/the U.S. Government's goals and objectives dependent on the development of a non-government-driven LEO market? If so, how big is this market and how much is the U.S. willing to invest to get it, and who is responsible for developing that market?
- Who is responsible for defining and certifying that commercially owned and operated orbiting facilities are safe?

While the answers to some of the above questions are not immediately related to risk management and safety, the answers to the questions will define the scope and work plans that must be developed. The scope informs organizational structure and budget requirements, both key elements of managing safety and determining risk posture. This is especially true in the case of ISS transition, which is already constrained given current plans, by the timeframe for implementation.

At the technical and operational level there are other key questions that the Agency must address as it executes the transition from the ISS to operations on commercially owned vehicles. Such questions include:

- What is the acquisition or investment approach that will allow the Agency to understand the risk they are accepting?
- How will the Agency address shared risks between the government and industry?
- Will the Agency need to plan an SE&I role and if so, what will be the role of NASA's workforce in LEO operations in the future and what skill sets are needed?

NASA has already started to address some of the technical and operational questions above and engage in commercial LEO transition activities. Axiom has been given a contract for use of an ISS port and currently anticipates installing its first module in the late 2025 timeframe. The company, with NASA's support, is also contracting private astronaut missions to the ISS to start developing organic experiences around managing human activities on orbit. NASA has also solicited other potential industry partners on their interest in providing an orbital laboratory capability, participating in discussions regarding concepts of operations, requirements, and examining lessons learned from previous commercial services procurement activities.

These activities are important and critical to help shape NASA's future demand for laboratory capabilities in LEO and to help industry decide if and how to engage with NASA and in LEO more broadly. But, in and of themselves, without the larger strategic questions addressed and a comprehensive understanding of the goals, resources, and scope of a transition plan, the current activities that NASA is engaging in are not guaranteed to be successful, and the Agency faces the possibility of a significant gap in its ability to execute in LEO.

Consequently, the Panel believes that NASA's activities in LEO can benefit from a similar approach in strategically outlining architecture, requirements, SE&I, and integrated schedule and program management as that being applied to the Artemis campaign. Such a similar construct would be useful for identifying and managing not only the technical risk associated with extending the life of the ISS, the technical and operational risk associated with certifying privately built orbiting laboratories for NASA use, but also for the programmatic and schedule risk that is inherent in trying to smoothly transition from ISS operations to a privately provided capability without a gap in NASA operations in LEO.

V. Ongoing Concerns

Preceding sections of this report discuss new recommendations made by the Panel in 2021, as well as newly emerging issues in 2022, including those that have significantly evolved in recent months. This section covers the status of ongoing concerns that the Panel has identified and discussed in previous annual reports and consequently been tracking for quite some time.

A. Commercial Crew Program

The Panel has engaged with both Commercial Crew Program (CCP) providers for many years. At present, the most significant high-level Panel concern about the CCP is that over ten years after it was established, the CCP is still essentially only a one-provider program. This places the ISS program in a prolonged state of elevated risk in the event that any disruption to SpaceX's crew delivery and return capability is experienced. The Panel, in previous public statements, has been an advocate for multiple U.S. providers as an overall strategy to support ISS operational risk reduction.

In 2022, the Panel had an opportunity to visit Boeing's facilities at the Kennedy Space Center (KSC). Boeing still faces a large volume of work that must be accomplished before proceeding to the first Crewed Flight Test (CFT), currently scheduled to launch in 2023, almost three years after the first uncrewed test. While the Panel frequently stresses the need to avoid any "rushing" to launch, which could result in compromising risk decisions, the continual delay also adds risk to the ISS program. Certainly, there is a risk balance that needs to be struck between the application of adequate resources and appropriate drive to accomplish mission objectives and launching at an appropriate time in a safe manner. The Panel has generally been pleased with a consistently expressed view that the program will proceed to CFT of the Starliner spacecraft when—and only when—they are ready. It is a nuanced balance, and the Panel will continue to monitor the situation.

Figure 2.
Boeing's CST-100 Starliner spacecraft making its way to SLC-41 Vertical Integration Facility at Cape Canaveral Space Force Station on May 4, 2022.

Another ongoing Panel CCP concern involves the planned launch co-location of both the mature SpaceX Falcon 9 and the future first-of-its-kind SpaceX Starship rocket from Pad 39A at KSC. While the potential for rocket mishaps can never be discounted, no matter how mature, a new heavy lift rocket such as the Starship must be considered a higher risk launch effort, pending demonstrated performance through repeated successes. Given its explosive potential, a Starship launch mishap could endanger and interrupt not only the Artemis launch cadence, but also the critical SpaceX crew missions to the ISS. The Panel is monitoring SpaceX's activities to mitigate this risk, which include:

- Hardening the vulnerable Crew and Cargo Dragon launch facilities against the estimated TNT yields of the Super Heavy booster to mitigate damage should a Starship launch mishap occur.
- Successfully demonstrating the Starship/Super Heavy ground and launch operations from the Boca Chica Starbase in Texas before moving operations to Florida.
- Modifying the KSC SLC-40 launch site to provide backup CCP crew and ISS cargo launch capability should Pad 39A not be available.

Figure 3.
The SpaceX Falcon 9 rocket, with a Crew Dragon atop, lifts off from Launch Pad 39A at KSC in Florida for NASA's SpaceX Crew-4 mission on April 27, 2022.

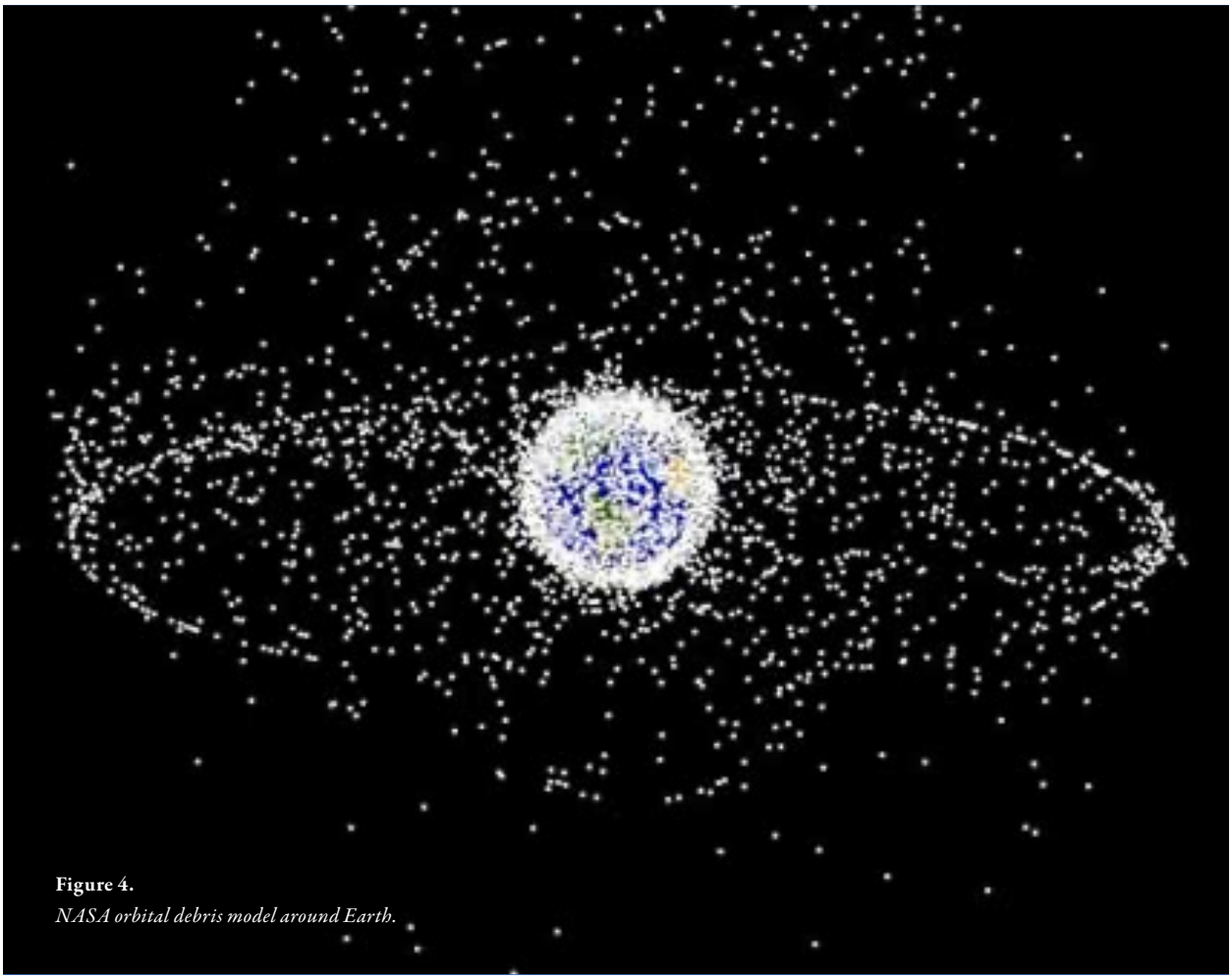

Figure 4.
NASA orbital debris model around Earth.

B. Micrometeoroids and Orbital Debris

The risk posed by micrometeoroids and orbital debris (MMOD) persists as the top threat to all human space flight programs. In fact, as of this writing, NASA is currently addressing an urgent situation with the Russian Space Agency that involves an on-orbit Soyuz that may have been struck by a micrometeoroid. In 2022, the Panel received input from the ISS program that additional MMOD generated by a November 2021 Russian anti-satellite (ASAT) test has put the ISS at even higher risk—perhaps as much as double the risk it was exposed to before the test event. Figure 5 illustrates the trend in conjunction events over the past decade and a half. Not only is debris an ongoing threat to the ISS and human space flight vehicles, but the increasing number of satellites present and transiting the ISS orbit is also of concern.

For years, the Panel has been monitoring this risk and has made recommendations for better controlling the hazard of potentially catastrophic collisions between human spacecraft and either MMOD or satellites.

In 2020, the Panel issued two related recommendations about designating a lead Federal agency for Civil STM. One of these recommendations, 2020-03-01, was for Congress, and the other, 2020-03-02, was for

NASA. Based on the thorough and appropriate response from NASA, and the proposed STM roadmap, the second recommendation, for NASA, has been closed.

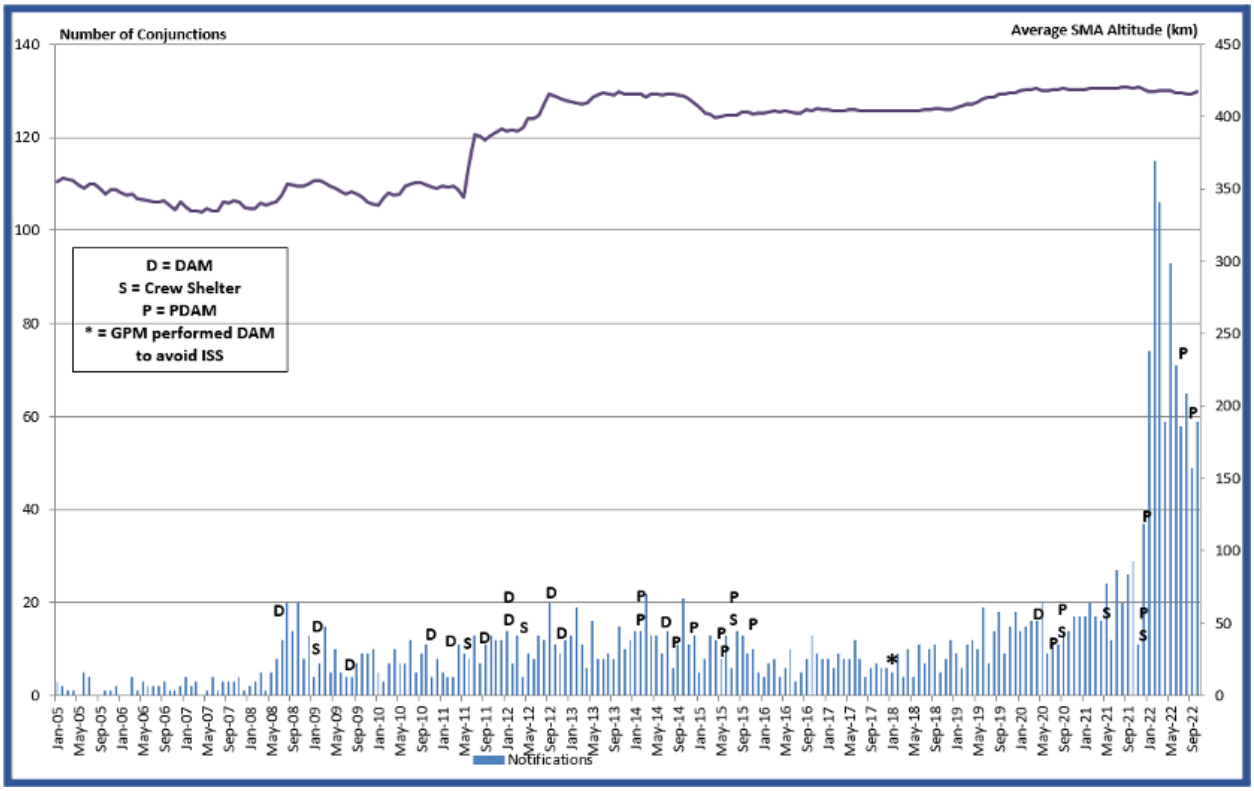

Figure 5.
Independent Conjunction Events: 2005–2022.

Regarding the recommendation for Congress, the Panel has noted some progress on this issue in 2022. There have been tentative discussions to appoint and appropriately fund a civilian U.S. government agency with the responsibility for civil Space Traffic Management (STM); to date, only the Department of Defense has been tasked with the responsibility to supervise orbital debris and notify satellite owners of evolving risks. Although industry is rising to this challenge with comprehensive technologies and operational algorithms, there is no U.S. government leader to develop and implement national STM policy and to lead a broad government/industry coalition to a better state of risk-managed outcomes. In May, the House of Representatives conducted a hearing on the topic of STM, and a bill was drafted calling for "transition to a civil space situational awareness capability." The Panel is leaving this recommendation for Congress open, pending legislation to assure a robust national STM capability.

C. Cybersecurity and Enterprise Protection

During 2022, the Panel had a chance to look more closely into ongoing concerns involving cybersecurity

and enterprise protection (EP). The Panel has seen some progress in establishing processes for EP, intended to remedy the most pressing flight vulnerabilities in the NASA enterprise.

The Panel has also seen tremendous strides in cybersecurity, and is pleased to note that NASA leadership strongly supports the Agency's activities in following *Executive Order 14028*, which lays out the following cybersecurity objectives:

- Protection of data, intellectual property, and digital IDs (e.g., cyber "hygiene")
- "Zero-trust" architectures
- Supply chain security
- Threat detection and capture of other "real-time" event data
- Promulgation of cybersecurity standards to include within Agency contracts

Previously, the Panel raised a number of concerns and issues during its reviews over the years, but progress has been notable, including:

- Centralizing information technology (IT) authorities and budget under the Agency Chief Information Officer, with the potential to standardize funding models for IT services across NASA.
- New Requirement for command encryption of all space systems (NASA-STD-1006).
- Selection of NASA's first enterprise-wide security contract.
- Creation of a cyber risk dashboard, enabling NASA leaders to use important monitoring tools.
- Notable improvements to NASA's internet "perimeter" to combat cyber-attacks.
- Significant reductions in vulnerabilities through judicious IT upgrades and standardization.
- Establishment of cyber risk education for employees and contractors.
- Assessment of flight hardware suppliers for supply chain security.
- Recognition as a U.S. government leader for IT supply chain risk management.
- Other efforts to enhance cybersecurity and EP through standards, policies and processes are in work, but not yet fully developed.

Amid the notable efforts to date, the Panel encourages NASA to link ongoing improvements and efforts in cybersecurity and EP to measurable outcomes that assure the closure of vulnerabilities. For example, the recently established EP community forum provides ample opportunity for discussions and exchange of information, but the proof of its value will be in the implementation of tangible change.

An important discussion point for 2023 is whether newly established processes quickly and judiciously improve the security posture of space systems across the Agency through changes of program management, resource commitments, and behavioral priorities.

In 2016, the Panel opened a recommendation for NASA to make it a matter of policy that priority be given to obtaining the appropriate level of security clearance for all personnel essential to implementing the EP program to include program managers who must ensure their programs meet evolving cybersecurity standards. In 2022, the Panel closed this recommendation based on information presented by NASA. Through an

audit of all program manager and key leader positions, job descriptions now document the requirement for security clearances, and after several years, those requirements have been met.

VI. Conclusions and 2023 Focus Areas

In summary, the ASAP finds that NASA has made great progress in 2022 toward addressing the Panel's concerns about strategic issues that bear substantively on safety and risk management—developing a strategic vision; managing the workforce for the evolving space exploration environment; establishing flexible and responsive acquisition strategies; communicating intentions internally and externally; managing Artemis as an integrated program; and pulling together as a cohesive entity to govern with all participants unified toward achieving the Agency's goals. That said, the initial steps the Agency has taken require continued effort to operationalize and execute. In addition, challenges remain to apply the leadership's vision to obtain widespread internalization within the Agency's culture as reflected in consistent and pervasive behavior.

Therefore, in its 2023 program of work, the Panel will engage NASA with emphasis on:

- Tracking and understanding the continuing maturity and development details to execute the Moon-to-Mars strategic objectives.
- Increased clarity of the evolving Artemis program structure for comprehensive risk and safety management, including refinements of the SE&I functions and the transitions from development to operations.
- NASA governance actions to align the Agency leadership in a unified and accountable manner toward mission objectives, including the application of resources—both workforce and infrastructure.
- Refinement of the approach to realizing a sustainable presence in LEO that addresses overall strategy and risk management.
- Probing for indicators of a healthy safety culture in the NASA workforce including addressing the challenges of a post-pandemic environment.

The Panel also intends to engage with its other constituent, the U.S. Congress, on continuing efforts to address:

- STM to mitigate the hazards of MMOD.
- Resolution of the approach to mishap investigation for human space flight.
- Defining a requirement that at least one Senate-confirmed leadership position at NASA be filled by an individual with sufficient acquisition experience to competently serve as the Chief Acquisition Officer.

The Panel will also be keenly intent on the findings of the Artemis I test flight and the corrective actions necessary to address risks prior to Artemis II, on the execution of Boeing's CFT, and on strides in EP.

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

2022 Recommendations

2022-05-01: Define an International Space Station (ISS) Deorbit Plan

Finding: Although discussions are ongoing between NASA and the Russian Space Agency to make the controlled deorbit plan more robust, the ASAP reiterates its concern first stated in 2012, about the lack of a well-defined, fully funded controlled re-entry and deorbit plan for the ISS that is available on a timeline that supports the planned ISS retirement. Furthermore, the Panel recognizes that the ISS partners are operating at risk, today, without the capability to deal with a contingency situation that would lead to a deorbit. The risk to public safety and space sustainability is increasing every year as the orbital altitudes in and around the ISS continue to become more densely populated by satellites, increasing the likelihood that an unplanned emergency ISS deorbit would also impact other resident space objects.

Recommendation: NASA should define an executable and appropriately budgeted deorbit plan that includes implementation on a timeline to deliver a controlled re-entry capability to the ISS as soon as practicable—to be in place for the need of a controlled deorbit in event of an emergency as well as in place before the retirement of the ISS—to ensure that the station is able to be de-orbited safely.

Rationale: The Panel had a previous recommendation, 2012-01-02, "ISS Deorbit Capability," which stated:

> **Recommendation:** (1) To assess the urgency of this issue, NASA should develop an estimate of the risk to ground personnel in the event of uncontrolled ISS reentry. (2) NASA should then develop a timeline for development of a controlled reentry capability that can safely deorbit the ISS in the event of foreseeable anomalies.
>
> **Rationale:** An unexpected, emergency event could precipitate the need to deorbit the ISS at any time. Timely development of the plan on how to respond to such a situation before it occurs will allow an optimum response and maximize the safety to the public in such a situation.

The ASAP closed the recommendation in 2020 based on the fact that there was conceptual agreement on an approach and a final agreement was imminent. Subsequent detailed discussions among the ISS partners have identified technical and operational issues which need further addressing, so the Panel is returning to this topic. The urgency, first highlighted in 2012, remains.

> **OPEN:** NASA's response not provided at time of ASAP Annual Report 2022 printing.

Open Recommendations from Prior Years

2021-05-01: Development of Agency Strategic Vision for the Future of Space Explorations and Operations

Finding: For NASA to continue its trajectory of success in the decades ahead, it must proactively plan for and manage its work in the presence of the numerous challenges, constraints, and risks inherent in the changing environment of the aerospace community.

Recommendation: NASA should develop a strategic vision for the future of space exploration and operations that encompasses at least the next twenty years, including potential alternative scenarios, that is driven by how the Agency is going to understand and manage risk in the more complex environment in which it will be operating.

- The vision should describe the role that NASA intends to play during that period and how it plans to engage with both commercial and international partners.
- NASA should assess the workforce, including the number, types, skills, experience, and responsibilities that will be required, and the infrastructure facility requirements, with a plan for managing changes needed to meet those requirements.
- NASA should also propose general criteria for evaluating "make, manage, or buy" decisions on future programs or projects.
- All aspects of the strategic vision and its implementation should be clearly and unambiguously communicated throughout the Agency.

Rationale: NASA is no longer the sole driver or customer for human space flight capabilities and related technology, nor is it the sole organization creating demand. NASA, however, still has a critical role and responsibility in the space sector, and the Agency's decisions, opinions, and direction have weight and merit in the industry and across the globe. Consequently, it is imperative for NASA leaders to establish a clear vision of the future and an understanding of the Agency's purpose to anchor its decisions today and tomorrow. A strategic vision, and a set of guiding principles—well communicated to NASA's workforce and stakeholders—will help the Agency navigate the new environments within which it must operate to execute government missions. In addition, such a top-down, strategically driven approach can expose and enable the organization to anticipate risks that otherwise might go unknown or unforeseen through an organic bottoms-up approach.

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As noted in this report, the NASA leadership team has invested a good amount of time and focus on this recommendation, publishing *NASA Strategic Plan 2022* and its *Moon to Mars Objectives*. The Panel views these as two foundational documents in support of this recommendation. Given the breadth of this objective, the Panel recognized it would be unlikely completed in 2022. However, the Panel applauds

the very good progress to date and will be looking for continued action and details noted in the main section of this Annual Report as the Agency moves towards closure of this recommendation.

2021-05-02: Establishment of an Agency "Board of Directors"

Finding: Over the decades, at various times with varying amounts of success, NASA leadership has sought to create an Agency-wide identity to foster greater coordination. There remains, however, a very strong and separate culture at each NASA Center, which drives the Centers to prioritize their own goals rather than those of the overall Agency. In turn, this creates pressure against the implementation of a strategic approach that aligns the whole organization to a common set of goals. Importantly, moreover, the resource flow remains Center-focused rather than optimized around integrated outcomes.

Recommendation: As a part of an overall risk management approach and in order to develop and execute its strategic vision for the future of space exploration, NASA should establish and provide leadership through a "board of directors" that includes the Center Directors and other key officials, with the emphasis on providing benefit to the Agency's mission as a cohesive whole, and not to the individual components of the Agency. The Board should act to identify the strategic risks and obstacles that NASA may encounter in executing its mission, evaluate Agency-level mitigation approaches, and align the efforts of all Centers to ensure desired outcomes.

Rationale: Although NASA has well-established executive management forums through which it deliberates various Agency decisions, it does not convene senior leaders as a strategic team with a holistic perspective on the Agency. Thus, the Panel recommends the Agency adopt a "Board of Directors"-like governance approach for its executives. Under this construct, the Administrator's most senior staff at Headquarters and the Center Directors would comprise an Agency steering committee with a deliberate Agency-level focus, rather than as representatives from and advocates for their areas of responsibility or field centers.

NASA could convene this team in various ways, but it need not be a new or separate forum. Rather, NASA should set different engagement expectations for these leaders when they meet, in that they should "leave their individual program and/or Center hats at the door," and focus on corporate-level challenges, opportunities, and decisions driven by the best interests of the Agency and its ongoing missions. This imperative to focus on the entirety of the enterprise can help support the tough resource decisions necessary to contend effectively with the challenges of stakeholder demands, inevitable schedule pressures, and budget constraints. With NASA's critical resources, workforce, and infrastructure largely managed at field centers incentivized to protect them, the Agency has struggled for many years to shift the workforce out of less critical work, or to divest obsolete facilities and infrastructure. This has added cost and manpower pressures to field centers that need margin for higher priority work, innovative solutions, and new opportunities. To escape the status quo—i.e., protecting budget, preserving the workforce configuration, maintaining every building and piece of major equipment—an explicit shift to an Agency-level focus is an essential start to reducing fixed costs and freeing more resources for new work in space exploration.

OPEN

2021-05-03: Establishment of an Artemis Integrated Program

Finding: NASA has deviated from previous program management "best practices" that have been hallmarks of successful strategic programs. During this past year, the Panel had numerous opportunities, during quarterly meetings as well as special discussions, to better understand how the myriad programs and projects that collectively contribute to the objectives of Artemis will be brought together as a cohesive campaign, and the Panel notes several deviations from NASA's history that give cause for concern. The ASAP finds three areas of concern:

- There is no top-level Artemis program, and therefore no Artemis Program Manager, to provide comprehensive and aligned integrated guidance that directs resources of all Artemis programs and projects in a cohesive manner to manage the overall risk.
- No Artemis prime integrating contractor exists in support of the NASA workforce.
- An unprecedented mix of acquisition approaches presents risk management challenges.

Recommendation: NASA should manage Artemis as an integrated program with top-down alignment, and designate a Program Manager endowed with authority, responsibility, and accountability, along with a robust bottoms-up, collaborative feedback process for both Systems Engineering and Integration (SE&I) and risk management.

Rationale: As with many of this nation's most successful strategic efforts, NASA placed priority on program management approaches that valued clear lines of authority, a coherent resource management approach, and a transparent yet comprehensive roadmap for integrated risk management. NASA has deviated from previous program management "best practices" that have been hallmarks of successful strategic programs. The Agency is attempting to manage the systemic risks of the Artemis enterprise in the structure they have adopted for Exploration Ground Systems, Orion, and the Space Launch System, without deliberately assessing whether that structure is best suited for the necessary purposes of broad integration and enterprise risk management. Concerns involving the absence of 1) a designated Program Manager with program management authority over all aspects of Artemis developments across the enterprise; 2) a designated Prime Integrating Contractor responsible for risk management integration; and 3) a congruent acquisition life-cycle approach suitable to ensure an overarching blueprint for acquisition, oversight requirements, and insight have prompted the Panel to advise NASA to gain clarity on how this deviation from previous program practices is achieving equivalent risk management outcomes.

OPEN

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, 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, 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.

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. The Panel 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 low-Earth orbit operations without fully functional EVA suits.

OPEN

Over the past year, NASA has executed its acquisition for an EMU flight suit using a creative indefinite delivery/indefinite quantity approach that provides flexibility to support both the lunar mission as well as a replacement for the current EVA suits that are much needed for the ISS mission. The Panel views this as good advancement on both requirements but will keep this recommendation open to observe further progress and execution in 2023.

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 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 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 2022 and beyond.

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 mal¬functions or mishaps, this plan must comply with specific language in the NASA Authorization Act of 2005 concerning Human Spaceflight 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 International Space Station 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 and the National Transportation Safety Board 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 Commercial Crew Program. 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 2022

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.

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, 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 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.

NASA's Response: NASA concurs on the recommendation to support and partner with the lead Federal agency for Space Traffic Management (STM) once one is selected. Since the National Space Council issued Space Policy Directive-3 (SPD-3), the National Space Traffic Management Policy, Congress has offered conflicting legislative proposals to address STM, none of which have become law. However, two recent events offer optimism that definitive congressional action may be forthcoming in 2021 or earlier. On August 20, 2020, the congressionally directed independent review by the National Academy of Public Administration was released, which states that the Department of Commerce (DOC) is "best suited to perform STM tasks within the federal government." In addition, on October 21, 2020, the Chairman of the Senate Committee on Commerce, Science and Transportation introduced the Space Preservation and Conjunction Emergency (SPACE) Act to authorize the DOC to provide space situational awareness (SSA) services to civil, commercial, and international space operators. 3 Pending congressional action, NASA is taking steps in the interim to address the ASAP recommendation, as outlined in detail below. Regarding astronaut and spacecraft safety, through the leadership of the Office of Safety and Mission Assurance (OSMA), NASA continues investing in characterizing and managing risks to spacecraft and astronauts from meteoroids and orbital debris. Specifically, NASA is investing in research and development (R&D) in more than 50 technical areas that could be applied to STM and SSA. Of these, only R&D related to orbital debris mitigation is specifically intended for STM and SSA application. In order of priority, the myriad of technical areas being funded can be grouped into four broad disciplines as they relate to NASA's investment in R&D in STM and SSA: 1. Orbital Debris Mitigation. Developing, maintaining, and updating orbital debris [and meteoroid] environment models and their associated uncertainties. Conducting measurements of the orbital debris environment and conducting other research as needed to support the development of the orbital debris (and meteoroid)

environment models. 2. Space Environment Monitoring and Awareness. Developing tools to characterize the space environment as a means towards producing improved orbit predictions and understanding spacecraft anomalies. 3. Prediction Algorithms. Enhanced computing (i.e., machine learning) to best leverage the increased quantity and quality of data that could be provided through improved and more prolific sensors and timing. 4. Sensors. Space, airborne, and ground-based sensors better able to remotely detect and characterize space objects with better perceptivity and resolution as well as reduced uncertainty over a wider range of observable aspects. Regarding development of guidelines for STM, the NASA Office of Chief Engineer (OCE) has developed two documents in support of the ASAP recommendation. One serves to capture best practices for ensuring safe space operations with respect to collision avoidance, and the other ensures future NASA missions continue to plan for and implement collision avoidance practices. The first document is a NASA Conjunction Assessment Handbook (HBK), now publicly available for use by all space operators. The HBK is the result of close collaboration with other agencies to establish a best practices document for collision avoidance and conjunction assessment topics. The document contains a variety of background, context, and technical information needed by space operators. The HBK addresses the full life-cycle of a typical spaceflight mission, from design considerations through launch and on-orbit operations. Departments and agencies consulted in developing the HBK material include the USSPACECOM's Strategy, Plans, and Policy Directorate; the 18th Space Control Squadron (18 SPCS); the Departments of Commerce and Transportation; and the Federal Communications Commission. The HBK was released in December 2020. Future updates to expand the HBK's coverage are expected in calendar year 2021 and later years as the industry continues to evolve. 4 This will also permit aligning the best practices with emerging space traffic management guidance by the selected lead agency. In parallel, OCE also developed a NASA Interim Directive (NID). While the HBK is a set of best practices for all space operators, the NID defines requirements for NASA's future near Earth human and robotic missions. This will ensure that NASA continues to serve as a leader in operating safely in space. Similar to the HBK, the NID requirements address various aspects of spacecraft design and operations, including ensuring trackability by the Space Surveillance Network, sharing of ephemeris information, proactively coordinating with other operators regarding systematic conjunctions (including human spaceflight), and defining minimum thresholds for mitigating a close approach.

The NID was approved and issued in November 2020. The NID contents will be updated and integrated into the permanent NASA policy framework in calendar year 2021. Finally, regarding development of a proposal for a STM technology roadmap, given the current and future investments in STM and SSA R&D and the pending best practices and requirements outlined above, OSMA and OCE will work with the Space Technology Mission Directorate throughout 2021 to outline a proposal for a STM-related technology roadmap, focused on gaps that are not being otherwise addressed. Further observations and discussions were held in 2022.

Based on the thorough and appropriate response from NASA and the proposed STM roadmap, this recommendation has been CLOSED.

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 International Space Station (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. crewmembers until such time that U.S. capability to deliver crew to the ISS is established.

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

NASA's Response: NASA concurs with the recommendation. NASA is actively developing, assessing and implementing options to protect for presence of crew on the ISS to support the United States On-orbit Segment (USOS). NASA continues to monitor launch schedule and is developing options to provide schedule margin by protecting USOS presence if CCP's currently launch dates are delayed beyond the return of U.S. crews on Soyuz. NASA continues to work with ROSCOSMOS on Soyuz crew. Current plans have USOS presence on ISS through January 2020. In parallel, NASA is working with the U.S. Commercial Crew providers on options that allow for mission extension of the crewed flight tests to support USOS crews on ISS for longer periods of time. NASA continues to remain focused on working together with the providers to meet schedules for U.S. crewed missions to the ISS. In parallel, NASA will continue to look for backup options to maximize USOS presence in case of contingencies.

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." Based on the SpaceX flights and recent seat exchange agreement with Russia, this recommendation has been CLOSED.

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.

NASA's Response: NASA concurs with the recommendation. NASA is establishing clearance requirements within the governance management system of the Enterprise Protection Program. The Charter of the Enterprise Protection Board, as part of the Enterprise Protection Program, lays out specific requirements for the Agency leadership and the proposed technical authority subject matter experts working within the Enterprise Protection Program. Specifically, the Enterprise Protection Board members and the technical authority subject matter experts will be required to maintain a minimum TS/SCI SV/TK//G//HCS classification level. Specific program and project management classification requirements will depend on the technologies and capabilities of those whose specific work effort may require more or fewer requirements than those of the Enterprise Protection Board or the subject matter expert technical authorities. Further, NASA recognizes that the threat environment that it works within is changing continuously and that NASA must be vigilant to those changes and be open to modifying its clearance requirements in order to adequately address those malicious risks.

In 2022, NASA presented that through an audit of all program manager and key leader positions, NASA job descriptions now document the requirement for security clearances, and after several years, those requirements have been met.

Based on the information presented by NASA in 2022, this recommendation has been CLOSED.

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 at 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.

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

- Examinations Director, Board of Certified Safety Professionals (BCSP)
- Executive Vice President, International System Safety Society (ISSS)
- Member, Personnel Certification Accreditation Committee of the ANSI National Accreditation Board
- Form Vice President and Deputy Operation Manager, Science Applications International Corporation (SAIC)
- Former Chair, G-48 System Safety Committee of SAE International

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, 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.

For many years, West actively led or supported standards-developing activities for system safety and other specialty engineering disciplines. From 2010 to 2019, he 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. Mr. West served on the BCSP Board of Directors from 2008 to 2013 and was the Board's Treasurer from 2012 to 2013.

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. He 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.

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). West enjoys astronomy, bicycling, and traveling.

Richard S. Williams, MD, MPH, FACS

- Director, Three Rivers Health District, Virginia Department of Health
- Director, Eastern Shore 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 and the Eastern Shore Health Districts of the Virginia Department of Health. He leads 12 public health departments serving a 2,500-square-mile rural area in Virginia's Middle Peninsula, Northern Neck, and Eastern Shore, responsible for public health care and environmental health support to a population of about 183,000. He is also a Federal Aviation Administration Senior Aviation Medical Examiner, 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.

William P. Bray

- Vice President, Strategic Business Operations, Frontier Technology Incorporated
- Former Deputy Assistant Secretary of the Navy for Research, Development, Test and Evaluation
- Former Executive Director, Navy Program Executive Office (PEO) for Integrated Warfare Systems (IWS)
- Former, Director for Integrated Nuclear Weapons Safety and Security at Navy Strategic Systems Program, Direct Reporting Program Management (DRPM) Office

William P. Bray is currently the Principal at W. P. Bray Consulting, LLC, providing independent consultant services to the defense and aerospace community. In the prior two years, he served as the Vice President for Strategy and Business Integration at a defense data analytics company.

In 2020, Mr. Bray retired after 36 years of government service, the last 14 years serving in the Senior Executive Service Corps. His last assignment was as the Deputy Assistant Secretary of the Navy for Research, Development, Test and Evaluation (DASN (RDT&E)) under the Assistant Secretary of the Navy for Research, Development and Acquisition (ASN RD&A). In that role, Mr. Bray was responsible for executive oversight of all matters related to Naval RDT&E Budget Activities, Science and Engineering, Advanced Research and Development, Prototyping and Experimentation, and Test and Evaluation. In addition, he was responsible for oversight and stewardship of the Department of Navy Research and Development Establishment which included Naval Laboratories, Warfare Centers, and Navy University Affiliated Research Centers.

Prior to the DASN RDT&E position, Bray was the Executive Director for PEO IWS, where he directed the acquisition and Fleet support of the Surface Navy's combat systems, weapons, radars, and related international and foreign military sales programs. Other leadership roles within the Navy included the Director, Integrated Nuclear Weapons Safety and Security at the Navy Strategic Systems Programs Office, and Major Program Manager (MPM) for Surface Navy Combat Systems. Mr. Bray started his career at the Naval Surface Warfare Center, Corona Division, California in December 1984.

Bray is a graduate from The Pennsylvania State University in 1984 with a Bachelor of Science degree in Petroleum and Natural Gas Engineering, and also earned a Master of Science in Systems Management from the University of Southern California. He was Defense Acquisition Workforce Improvement Act (DAWIA) Level III certified in Program Management, Engineering, and Test and Evaluation. During his government career, he received a Meritorious Executive Presidential Rank Award in 2018, the Navy Distinguished Civilian Service Award in 2017 and 2020, and the Navy Superior Civilian Service Award in 2013.

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 currently the Principal at AstroPlanetview, LLC and a part time Professor of the Practice at the Georgia Institute of Technology. Before joining Ga Tech she was the Deputy Director of Engineering in the Office of the Secretary of Defense for the Undersecretary of Research and Engineering. In that role she served as the "Chief Engineer" for the DoD establishing engineering policy, propagating best practices and working to connect the engineering community across the department. In addition, she is the former Executive Director of the American Institute of Aeronautics and Astronautics (AIAA), the world's largest technical society dedicated to the global aerospace profession. Prior to leading AIAA, Dr. Magnus was a member of the NASA Astronaut Corps for 16 years.

Born and raised in Belleville, Ill., Dr. Magnus attended the Missouri University of Science and Technology, graduating in 1986 with a degree in physics and earning a master's degree in electrical engineering in 1990. 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, Office or 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).

Paul Sean Hill

- Independent Consultant, Author, Speaker, and Principal of Atlas Executive Consultant, 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, he 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, Hill 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, Hill 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.

Dr. Amy Donahue

- Provost and Chief Academic Officer, Unites States Coast Guard Academy
- Professor emeritus of Public Policy, University of Connecticut
- Former Senior Advisor to the Administrator for Homeland Security at NASA

Dr. Amy Donahue is Provost and Chief Academic Officer at the United States Coast Guard Academy. Dr. Donahue provides primary leadership and direction for all academic activities and faculty affairs at the Academy.

Dr. Donahue is professor emeritus of public policy at the University of Connecticut (UConn) where her research has focused on executive leadership, homeland security, and disaster preparedness. She was principal investigator on research funded by the Department of Homeland Security as part of the Center of Excellence for the Study of Natural Disasters, Coastal Infrastructure and Emergency Management.

From 2011 to 2018, Dr. Donahue served as UConn's Vice Provost for Academic Operations and Chief of Staff to the Provost. Prior to that, Dr. Donahue headed UConn's Department of Public Policy. Previously she advised the Chancellor of Louisiana State University immediately following Hurricane Katrina and was the founding director of LSU's Stephenson Disaster Management Institute.

From 2002 to 2004, Dr. Donahue was Senior Advisor to the Administrator for Homeland Security at NASA and, as the agency's liaison to the Department of Homeland Security and the Homeland Security Council, was responsible for identifying opportunities for NASA to contribute to homeland security efforts across government. In 2003, she had a major leadership role in the field response to the Columbia mishap. From 2004 to 2007, Dr. Donahue served on the Aerospace Safety Advisory Panel and was recently reappointed to the Panel.

As the Distinguished Military Graduate of Princeton's Reserve Officer Training Corps in 1989, she began her U.S. Army career in the 6th Infantry Division at Fort Wainwright, Alaska. Her military assignments included serving as Officer in Charge of a Forward Surgical Team, as the Training and Operations Officer (S3) for the 706th Main Support Battalion, and as Chief of Mobilization, Education, Training, and Security for Bassett Army Hospital. She moved on to manage a 911 communications center, and to volunteer part-time as a firefighter and medic in Fairbanks, Alaska and upstate New York.

Dr. Donahue holds her Ph.D. in Public Administration and her M.P.A. from the Maxwell School of Citizenship and Public Affairs at Syracuse University. She graduated magna cum laude with a B.A. in Geological and Geophysical Sciences from Princeton University. She was elected a fellow of the National Academy of Public Administration in 2011. She is certified as a Wilderness Emergency Medical Technician.

Dr. Mark N. Sirangelo

- Scholar in Residence for Space, Aerospace and Engineering at University of Colorado
- Founding executive and Former Head of Sierra Nevada Space Systems
- Founding member and past Chairman of the Commercial Spaceflight Federation
- Founder and Chairman of eSpace, a nonprofit, that supports the start-up and growth of space technology companies

Dr. Mark N. Sirangelo currently is the Scholar in Residence for Space, Aerospace and Engineering at University of Colorado. He is also on the Tuskegee University Aerospace Advisory Board and is a visiting

professor at Syracuse's Maxwell School of Citizenship and Public Affairs. Dr. Sirangelo has over a two-decade space industry executive career having led teams which have successfully managed billions of dollars of space programs for over 300 U.S. based space missions. In addition to academia, he provides industry advisory and board services through his company QuanStar Advisors, LLC.

In the space industry, he was the founding executive and head of Sierra Nevada Space Systems for over 10 years until 2018. Previously, Dr. Sirangelo was the Chairman & CEO of SpaceDev, a publicly traded commercial space company that he grew from early stage until its merger with SNC. SpaceDev and SNC had many space firsts, including being on the inaugural winning X-Prize team and the design, build, launch and operation of one of the first small satellites.

Dr. Sirangelo was a founding member and past Chairman of the Commercial Spaceflight Federation, which currently represents over 85 space organizations. He has been inducted as an Associate Fellow of the American Institute of Aeronautics and Astronautics and served on the executive board of the Aerospace Industries Association.

Dr. Sirangelo served for three years as the Chief Innovation Officer of the State of Colorado, a Cabinet level position. He is the most recent past Chairman of the U.S. Department of Defense's Defense Innovation Board providing advice to the office of the Secretary of Defense and the founding and past Chair of the DOD's Space Advisory Committee. Previously, he completed an assignment as Special Assistant to the NASA Administrator helping to develop NASA's return to the Moon.

Dr. Sirangelo and his organizations have been recognized with numerous corporate and personal awards. These include being inducted into the Space Foundation's/NASA Technology Hall of Fame, the World's Top 10 Innovative Space Companies by Fast Company, being named Manufacturer Builder of the Year by ColoradoBiz magazine, The Best Place to Work by the Denver Business Journal, Inc. Magazine's top 200 companies, Defense Industry's Fast Track 50, Deloitte's Fast Track 500 and selected as a finalist in Ernst & Young's Entrepreneur of the Year.

One of the ways Dr. Sirangelo gives back to the space industry is as the founder and Chairman of eSpace, a nonprofit, that supports the start-up and growth of space technology companies. As a personal passion, Mark has worked for over two decades to make the world a safer place for children as a founding Board member of the National Center for Missing and Exploited Children (NCMEC) which has resolved over 100,000 missing children's cases to date.

Dr. Sirangelo has a multi-faceted personal background including being a long-term licensed pilot and a successful creative artist. He holds Bachelor of Science, MBA and Doctorate level degrees and has served his country proudly as a U.S. Army officer.

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 Pettit
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 an information security technical writer for the Texas Department of Transportation in Austin, Texas.

Annex A: Aerospace Safety Advisory Panel (ASAP) Review of X-Plane Test Program Safety

I. Background

On October 18, 2022, ASAP members visited the Armstrong Flight Research Center (AFRC) to receive an overview and status of the X-Plane program per the request of Ms. Pam Melroy, NASA Deputy Administrator. ASAP members participating in the visit included Mr. William Bray, Dr. Mark Sirangelo, and Dr. Richard Williams. Ms. Carol Hamilton, ASAP Executive Director, attended as well. Dr. Sirangelo and Ms. Hamilton were present on-site at Armstrong and Lockheed Skunkworks while Mr. Bray and Dr. Williams participated virtually. AFRC attendees and agenda are provided in the Addendum A.

II. Discussion

The focus of the discussion was NASA X-plane projects with a detailed discussion and status report of the X-59 Quiet SuperSonic Technology (QueSST) program, and a brief X-57 discussion during the tour. The ASAP focused on several aspects to include Armstrong personnel and experience, certification approach and process, X-59 program risks and hazards, and X-57 program status. Here is a summary of pertinent insights and findings:

1. **Personnel.** Generally, the AFRC leadership and personnel associated with the program appear to be experienced and well immersed in the design and technical issues. Although AFRC has not built X-planes in the recent past, it has maintained technical competency through leadership and technical participation in other test plane programs. Having leadership stability and constancy of purpose at AFRC going forward will minimize workforce uncertainty and churn as these programs hit critical execution milestones.

2. **Certification and technical authority processes.** The AFRC team reviewed its policies, procedures, standards, and application of technical authority for X-plane development and operations with the ASAP representatives. The policies, procedures, and standards are well documented, stable, and well proven. Technical authorities, via the Chief Engineer, Safety and Mission Assurance, and Chief Health and Medical Officer, have been involved with the program from X-59 program initiation in accordance with its policy and related procedures. The ASAP participants did not identify any immediate issues or concerns here.

3. **X-59 risks/hazards.**
    a. **Design Approach.** In order to reduce costs and increase timeliness, the X-59 program was designed with an approach that would incorporate many previously designed and flown sub-components, as shown on Figure 1 below. Although this approach was intended to reduce costs and improve timeliness to delivery, it creates safety and technical risk relative to the systems/components integration into the overall total system design. Although AFRC recognizes this as a risk and has already begun working several such issues, it should be an area for continued focus

and review for the Agency, AFRC, Technical Authority leadership, and the Lockheed Martin team leading into flight testing.

Figure 1.
Drawing depiction of the X-59 QueSST aircraft features.

b. **Other technical risk and safety hazards for consideration.**

i. ***Pilot has no forward external view except via external remote cameras.*** Again, as evident in Figure 1, to achieve the desired performance objectives, the design of the X-59 aircraft does not allow for the pilot to have a view forward. The aircraft does have airframe-mounted cameras with some redundancy for the pilot to view the external environment. In addition, the program has developed a now functional flight simulator to ensure the pilot has sufficient training with respect this design concept. The lack of direct forward visibility creates a level of added risk for review and mitigation as the aircraft moves from fabrication to flight testing, particularly in conjunction with the next risk discussion topic.

ii. ***Aircraft clearance at take-off/landing.*** Given the elongated nature of the design, the amount of aircraft aft clearance to the ground on take-off and landings is extremely small (approximately 5-9 inches). This risk will require extreme care and precision on aircraft

take-off and landing. In addition, there are no landing braking assist parachutes or speed reduction devices currently on the airplane, therefore requiring long straight-in landings at high speeds and a need for the appropriate length runways, which are found at Edwards Air Force Base. The AFRC team has identified this as a risk and has implemented measures to mitigate, including simulator training. This represents another technical and safety risk which needs to be closely monitored in the transition to and through the flight-testing regime.

iii. ***Test Approach.*** The test plan briefed provided a graduated series of flight tests that would build confidence in the aircraft, its performance, and pilot operations. This seemed to be a reasonable and responsible test approach for an experimental aircraft. Of note, a Lockheed Martin pilot will fly the initial flight tests. Also, there is only one airframe planned to be produced, thus meaning that any serious incident will likely mean the end of the test program.

c. **Programmatic Risks.** Although the X-59 program is approaching aircraft delivery and testing, cost and schedule projections are under significant pressure. Funding to execute is tight, but, according to the Program Manager, sufficient to execute the current plan. The contract is a cost-plus incentive fee. The ASAP considers this a programmatic and budget watch item.

d. **Challenges to meeting Program Performance Objectives.** The overall goal of the X-59 program is to collect "data that could make supersonic flight over land possible, dramatically reducing travel time in the United States." This qualitative objective has been translated into a quantitative objective of 75 Perceived Level Decibels (PLdB), equivalent to a car door slam from a distance of 20 feet. The ability to achieve this goal is still in question. Modeling of the design indicates it will achieve this goal; however, until the aircraft is available and has undergone ground-based testing, it will not be known if it is achievable. This testing should occur over the next six months. Having said that, the ASAP believes moving forward with the flight testing of the aircraft will provide invaluable insight. The data collected will be informative and will provide good quality learning and understanding of what is achievable in this regime. The ASAP recommends engagement with the broader aircraft industry to understand what is being done today and to ensure the learning and data collected on the X-59 program is shared with industry, and vice versa. Although this effort will inform what is achievable, the ASAP encourages the Agency to understand the Federal Aviation Administration requirements and the supporting data required to relieve the current standards. As was presented to the ASAP, the current U.S. regulations prohibiting or reducing non-military or emergency supersonic travel over the continental U.S. are not based upon measured sound levels but rather based strictly on flight speed with the upper limited being the speed of sound or around 740 mph at 32 degrees Fahrenheit.

e. **Human Systems Integration (HSI) and Health and Medical Technical Authority (HMTA).** The X-59 project team provided a good amount of detail regarding Human Systems Integration and the Health and Medical Technical Authority before and during this meeting. ASAP's

assessment is that the HMTA interface and ongoing support is appropriate, and the crew health risks have been identified, analyzed, and mitigated to levels that are accepted in other aircraft types and operations. A detailed report is attached as Addendum B.

4. **X-57 summary.** Generally, the X-57 program appears to have low-risk profile with its current configuration and program execution. The plane itself is a basic demonstrator aircraft of electric powered flight. Given current activity in industry regarding electric-powered aircraft and the design/configuration of the X-57, it brings into question what will be learned from the current program.

Figure 2.
Artist's conceptual view of the X-57 compared to actual X-57 in a hangar.

There has been a decision to simplify the program due to budget constraints. The program has reduced the overall scope to a simpler two-engine design utilizing a conversion of an existing available airplane based upon an Italian Tecnam P2006T. NASA has replaced the Tecnam's two Rotex motors with two electric motors. These two motors and their two 400-pound lithium-ion battery packs have been installed and ground tested. There have been some test program successes from the ground tests but there are others, including heat management, that need to be addressed prior to flight tests beginning in earnest. The ASAP recommends AFRC leadership engage industry to understand state of the art, state of the practice, and what has been learned to date as the aerospace industry is independently developing such designs and, in some cases, these designs appear to be more advanced than the NASA design efforts.

III. Summary

Overall, the visit to AFRC (both on-site and virtually) was an excellent opportunity to review their X-plane efforts. The AFRC team has been fully engaged in the projects, and the processes and procedures are well established and being followed for the design, development, and test of these experimental vehicles. Design of both the X-57, as simplified, and the X-59 is nearing next-phase completion for initial flight tests, and both

aircraft are in varying stages of fabrication leading to test. The ASAP recognizes that technical and safety risks are inherently built into the design at this point and there is little ability to mitigate other than through operational processes and procedures, training, and execution plans. The ASAP recommends attention to detail regarding all risks and particularly those mentioned in this report as both aircraft, and particularly the X-59, proceed to flight testing.

Addendum A: Agenda and Attendees

Attendees (not a complete list)

- AFRC: Bradley Flick, Acting Center Director; Eddie Zavala, Acting Deputy Center Director; Bradford Neal, Senior Technical, Advisor for Airworthiness and Flight Safety; CJ Bixby, Chief Engineer; Glenn Graham, Director, Safety and Mission Assurance
- ASAP: Mark Sirangelo, Rich Williams, William Bray
- NASA Advisory Council: John-Paul Clarke
- NASA Headquarters Office of Safety & Mission Assurance: Johnny Nguyen, Shun Tschen

Agenda

0800 – 0900	X-59 tour
0900 – 0945	Transit to main campus
0945 – 1000	Get settled
1000 – 1015	Formal introductions
1015 – 1100	AFRC 101
1100 – 1145	AFRC process overview
1145 – 1215	Lunch
1215 – 1415	X-59

- Mission overview brief (includes HSI considerations)
- Airworthiness and Flight Safety Review schedule
- Integration and test
  - System safety brief
  - Lifecycle identification and mitigation of hazards
  - Accepted risk hazards
  - Process applied to life support systems hazards and to an accepted risk hazard

1415 – 1715 X-59 simulator

- X-57 test airplane hangar visit, review and discussion of the program, challenges, and testing plans

Addendum B: X-59 ASAP Human Systems Integration and Health and Medical Technical Authority Review

The NASA Health and Medical Technical Authority (HMTA) has been involved with the X-59 program since 2017. The primary human health risks in the X-59 program relate to high altitude supersonic mission profiles. Aircraft egress during all phases of flight is also a concern. The HMTA leveraged extensive data and experience from military operations of similar flight profiles in its support of the X-59 program. NASA technical expertise was also engaged and utilized to fully understand the health risks attending X-59 mission profiles. The primary human health risks inherent to the program include:

1. Hypoxia
2. Decompression sickness (DCS) risk from:
    - Rapid decompression at altitude
    - Nominal operations with high cabin altitudes
3. High speed/high altitude egress
    - Time of decent in a hypoxic environment
4. Potential for White Matter Hyperintensities (WMH)

The X-59 utilizes legacy systems from other aircraft whenever feasible, including the T-38 aft cockpit. The T-38 has accumulated millions of flying hours over the past six decades, and from an anthropometric and cockpit ergonomics standpoint, it is a well-proven design. The cockpit uses a constant pressure deferential for cabin pressure; at a nominal mission altitude of 55,000 feet, the cabin pressure will be about 5.95 pounds per square inch (23,000 feet cabin altitude). The pilots will wear protective pressure garments similar to the F-22 system, which, are in effect, partial pressure suits. Breathing oxygen is delivered under pressure from a liquid oxygen system; the aircraft does not use an onboard oxygen generating system.

The risk of hypoxia during nominal operations is mitigated by the aircraft oxygen system and partial pressure garment. The risk of decompression sickness related to X-59 operations was extensively evaluated by the NASA Extravehicular Activity (EVA) Integrated Product team. DCS risk is mitigated to a great extent by the limited time at which maximum hypobaric exposure occurs during flight. The program will also incorporate a 30-minute oxygen pre-breathe period pre-flight to reduce nitrogen burden. The risk of DCS with rapid decompression is mitigated by the ability to descend immediately. The team concluded that the risk of Type l DCS during nominal X-59 mission profiles was 5% or less, and the risk of Type ll DCS was 1% or less, with the risk further reduced in sequential same-day sorties. This risk is well below the risk NASA accepts for EVA activities; the risk was deemed by the HMTA to be sufficiently small enough to not recommend any further mitigation.

Egress risk at high speed and high altitude is addressed by the Martin Baker ejection seat. There have been some challenges in adopting this system into the X-59, but NASA Armstrong and Lockheed Martin appear to believe that this has been accomplished. Although it is a well-known system, it has not been tested in this

configuration. Egress risk will be lowered by decreasing both the altitude and airspeed prior to ejection if possible. If there is an ejection at high altitude, the crewmember would take longer to descend to an altitude safe for normal breathing than accommodated by the T-38 ejection seat design; the X-59 program added a second oxygen bottle to the ejection seat to allow for the increased descent duration. The ejection seat performance envelope encompasses every phase of X-59 flight; the pilot can safely egress the aircraft at any time.

The risk of WMH was addressed separately with HMTA personnel. Recent studies have shown a correlation between the number of WMH in the brain and exposure to high altitude flight. Most of the studies have looked at military high-fliers (mainly U-2 pilots). This has led the United States Air Force to undergo a fleet-wide cabin modification of their U-2 aircraft to lower the cabin altitude. The HMTA looked at the medical literature, the military flight operations, and the limited high-altitude exposures proposed in X-59 operations, and ultimately concluded there was not sufficient rational to recommend any changes for the X-59 program.

In summary, the X-59 program authorities have pursued appropriate HSI activities through the duration of the program thus far and they maintain close interface with the NASA HMTA. Human health and medical risks are mitigated to (or lower than) precedents established in other, similar NASA and military operations.

Cover Image: *Pillars of Creation*
James Webb Space Telescope

Spacewalk outside the International Space Station

Orion crew capsule assembly at Kennedy Space Center

Prelaunch testing of Orion safety systems

SLS rocket for Artemis I inside the Vehicle Assembly Building at Kennedy Space Center

NASA officials participate in a media briefing

Astronaut performs launch pad abort/evacuation testing of Orion

Aerospace Safety Advisory Panel

Dr. Patricia A. Sanders, Chair
Mr. William P. Bray
Dr. Amy K. Donahue
Lieutenant General Susan J. Helms, USAF (Ret.)
Mr. Paul S. Hill
Dr. Sandra H. Magnus
Dr. Mark N. Sirangelo
Mr. David B. West
Dr. Richard S. Williams

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NP-2023-01-3098-HQ