Aerospace Safety Advisory Panel

Annual Report for 2015

NASA AEROSPACE SAFETY ADVISORY PANEL
National Aeronautics and Space Administration
Washington, DC 20546
VADM Joseph W. Dyer, USN (Ret.), Chair

January 13, 2016

The Honorable Charles F. Bolden, Jr.
Administrator
National Aeronautics and Space Administration
Washington, DC 20546

Dear Mr. Bolden:

Pursuant to Section 106(b) of the National Aeronautics and Space Administration Authorization Act of 2005 (P.L. 109-155), the Aerospace Safety Advisory Panel (ASAP) is pleased to submit the ASAP Annual Report for 2015 to the U.S. Congress and to the Administrator of the National Aeronautics and Space Administration (NASA).

This Report, which was completed prior to enactment of the fiscal year 2016 budget, is based on the Panel's 2015 fact-finding and quarterly public meetings; insight visits and meetings; direct observations of NASA operations and decision-making; discussions with NASA management, employees, and contractors; and the Panel members' past experiences.

We are gratified to report that, this year, we are better informed on the Commercial Crew Program (CCP) and can positively report on its certification and safety-associated processes. The NASA leadership developed a workaround that supports direct communications with the CCP Program Manager rather than via the Director of Commercial Spaceflight Development. Open communication and transparency have proven essential to advancing the safety of the Program—both in cooperation with the ASAP and, most importantly, internal to NASA. The Panel continues to steadfastly believe competition is essential to achieving a safe and productive CCP future. The Orbital-3, SpaceX CRS-7, and Russian Soyuz/Progress 59 cargo accidents underscore this position.

The three cargo accidents, and resulting loss of resupply missions, yielded a challenging year for the International Space Station (ISS), but NASA's outstanding planning and logistics stewardship of the ISS overcame the tribulations.

In this year's report, you will see the ASAP's increased focus on the Exploration Systems Development (ESD) endeavor. Financial and perceived schedule pressures are impacting safety and design considerations. Although in past years, ESD has received more appropriations from Congress than requested, the Orion and Space Launch System Programs are at a crucial stage where schedule constraints and funding profiles are starting to have significant safety implications. Safety is directly linked to the sufficiency and timing of funding needed to execute NASA's programs. We continue to be impressed with how much the Agency accomplishes with relatively little. The annual uncertainty associated with funding level and late appropriations also create an additional strain on program planning and ultimate safety. The Congress can support improved safety with more robust funding and with better budget profiling.

We salute NASA's many contributions in broad mission and organizational areas as well as human space flight. The flyby study of Pluto and its moons in summer 2015 highlights what the women and men of NASA can do. This, and other specific accomplishments, are highlighted in the report.

NASA's senior leaders and staff members offered significant cooperation throughout the year and support to the completion of this document. I submit the ASAP Annual Report for 2015 with respect and appreciation.

Sincerely,

VADM Joseph W. Dyer, USN (Ret.)
Chair, Aerospace Safety Advisory Panel
Enclosure

NASA AEROSPACE SAFETY ADVISORY PANEL
National Aeronautics and Space Administration
Washington, DC 20546
VADM Joseph W. Dyer, USN (Ret.), Chair

January 13, 2016

The Honorable Joseph R. Biden
President of the Senate
Washington, DC 20510

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National Aeronautics and Space Administration
Washington, DC 20546
VADM Joseph W. Dyer, USN (Ret.), Chair

January 13, 2016

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

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Preface

The Aerospace Safety Advisory Panel (ASAP) was established by Congress in 1968 to provide advice and make recommendations to the NASA Administrator on safety matters. The Panel holds quarterly fact-finding and public meetings and makes "insight" visits to NASA Field Centers or other related sites. It reviews safety studies and operations plans and advises the NASA Administrator and Congress on hazards related to proposed or existing facilities and operations, safety standards and reporting, safety and mission assurance aspects regarding ongoing or proposed programs, and NASA management and culture issues related to safety. Although the Panel may perform other duties and tasks as requested by either the NASA Administrator or Congress, the ASAP members normally do not engage in specialized studies or detailed technical analyses. The ASAP Charter is included as Attachment 1 on the enclosed CD.

This report highlights the issues and concerns that were identified or raised by the Panel during its activities over the past year. The Panel's open recommendations are summarized in Appendix A, and the full text of all the recommendations submitted to the Administrator during 2015 is included as Attachment 2 on the CD. The 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

This Aerospace Safety Advisory Panel 2015 Annual Report to the NASA Administrator and to the Congress focuses on safety and opportunities for improvement, but also notes specific examples of the Agency's many accomplishments. The Report's focus must not detract from the Panel's deep appreciation for NASA contributions to the United States of America and to the world body of knowledge. The Agency has no peer in looking towards the beginning of the universe, understanding and protecting the world's environment, and sustaining the spirit of human exploration. NASA delivers true value for the taxpayers' money.

This year's Report reflects a partial shift in the Panel's prime focus from the commercial space programs to Exploration Systems Development (ESD). Stronger focus on ESD was encouraged by the NASA leadership. This is appropriate, as ESD programmatic and system design decisions are now being made that will impact exploration for the next 40 years. In the pages that follow, readers will see specific discussion of ESD-related risk and risk management. Even at this relatively early stage, schedule pressures appear to be impacting safety.

Commercial space programs remain a highly important topic worthy of sustained scrutiny. The commercial cargo accidents suffered during late 2014 and 2015—by Orbital ATK, SpaceX, and the Russians—highlight the challenges of space flight. The SpaceX and Boeing commercial crew systems are not yet certified, and schedule pressure is building on the way to first flights. The Panel remains steadfast in believing competition is the key to both safety and success.

The International Space Station (ISS) celebrated its 15-year anniversary of continuous human presence in low-Earth orbit and continues to surmount challenges and operate safely. The ISS Program's ability to sustain the loss of three cargo deliveries pays tribute to the concepts of risk management and logistics planning.

Funding remains a challenge for NASA as it strives to do so much with so relatively little. In Part III, we have highlighted our concerns with NASA's budget for the Commercial Crew Program and ESD.

NASA faces another challenge that has historically led to disruption and inefficiency and arguably has impact on safety and good systems engineering. This is the challenge of starting over with new programs and directions following Administration change. As in prior reports, the ASAP urges constancy of purpose. Failing to stay the course with current programs of record will make it an even longer, costlier, and potentially less safe trip to Mars.

II. Accomplishments in 2015

A. Commercial Crew Program (CCP)

Over the past year, the Panel has seen significant improvement in the CCP's openness and transparency. Specifically, the Panel commends the efforts of the CCP Program Manager in this regard as well as the support from senior NASA management. The discussions have been much more thorough and have focused on the Panel's particular concerns. The challenges and progress on the Program have reinforced the Panel's belief in the value of maintaining competition, which the Panel strongly supports. In addition, we note that the CCP continues to work the delicate balance between ensuring NASA's responsibility for crew safety and permitting the commercial providers to further their solutions for mission success without overly constraining those solutions.

B. International Space Station (ISS)

In early November, the ISS crew celebrated 15 years of continuous human presence in low-Earth orbit. The openness and transparency of the ISS Program have built confidence within this Panel and with others that the program management is in command of the issues. The Program addresses each issue that arises, solves the problem, learns from the experience, adjusts procedures and technologies appropriately, and applies the emerging knowledge to future endeavors. The ISS Program has shown itself to be a learning organization. In addition, the Panel is impressed with the Program's response to recent cargo launch failures—Orbital-3, SpaceX CRS-7, and Soyuz/Progress 59—that were primarily out of its direct control. Transportation planning and inventory is an incredible balancing act. The Program's ability to continue ISS operations and scientific research after the loss of three ISS support missions is a tribute to the ISS planners and logisticians. On an ISS mission under the Cargo Resupply Services contract with NASA, Orbital ATK's Cygnus spacecraft, launched aboard an Atlas V rocket, docked safely at the Station in December after recovering from a launch accident in 2014.

C. Exploration Systems Development (ESD)

ESD continues to make progress in all three programs—Orion, Space Launch System (SLS), and Ground Systems Development and Operations (GSDO). Over the past year, milestones accomplished include: completion of the seven-test series for the RS-25 engine at Stennis Space Center, a qualification solid rocket motor test in March, upgrading the mobile launcher to handle the new stack, Exploration Mission-1 pathfinder first

Figure 1. RS-25 Engine Test at Stennis Space Center

weld at Michoud Assembly Facility, crew module structural test at Glenn Research Center, and arrival of the European Service Module structural test article for Orion at NASA's Plum Brook test facility. As ESD transitions from design to hardware development, we believe that all three programs are progressing successfully. The SLS has completed its Critical Design Review (CDR), an important milestone. Orion and GSDO are currently going through their CDR processes.

D. Facilities Management

Last year, the Panel was impressed by the systems-based approach being used at the Marshall Space Flight Center. Several other NASA Centers have adopted similar approaches. The Johnson Space Center is using a systems-based approach to managing facilities to be more energy-efficient and economical as well as make more prudent use of the space available. It is taking a long-term approach and working with collaborative partners. This is similar to what the ASAP saw at the Langley Research Center—replacing infrastructure with newer, more efficient facilities, rebuilding for the future, and supporting emerging needs and new technologies. The people at the Kennedy Space Center deserve much credit for the planning, preparation, and hard work to transform the Shuttle Landing Facility into a vibrant and commercial spaceport. Great examples of good work could be made even better if best practices were to be shared across all NASA Centers.

E. NASA Engineering and Safety Center (NESC)

The ASAP applauds the NESC organization. The NESC has established itself as the "value added" independent test and analysis organization for the Agency, with over 600 assessments in 11 years. The workload remains high and is distributed across all of the missions. Many programs have been requesting support from the NESC. This speaks volumes for how well it is doing and the expertise it provides.

F. Other NASA Accomplishments

New Horizons, the first mission to the Pluto system and the Kuiper Belt, conducted a 6-month-long reconnaissance flyby study of Pluto and its moons in summer 2015, culminating with the closest approach to Pluto ever reached—within 8,000 miles.

The Mars Exploration Program continues to advance our learning about Mars. Curiosity rover has traveled to new sites for investigation. The instrument suite on the rover has made the first detection of nitrogen on the surface of Mars through measuring its release by heating samples of Martian sediments. The Curiosity rover team has found evidence of what may be ancient lakes on the Red Planet. New findings from NASA's Mars Reconnaissance Orbiter provide the strongest evidence yet that liquid water flows intermittently on present-day Mars.

Data from NASA satellites, instruments, and studies are answering important questions on climate and weather. The Soil Moisture Active Passive observatory, designed to collect global observations of soil moisture, began a 3-year mission that will expand our understanding of a key component of the Earth system that links the water, energy, and carbon cycles.

III. Funding Adequacy and Profiles

As we noted in our 2014 Annual Report and continue to assert this year, NASA's budget is insufficient to deliver all current undertakings with acceptable programmatic risk. Programmatic risk can lead to tradeoffs that are inconsistent with good safety practice. Historically, most successful programs have reflected a bias towards robust, early funding to support critical design and system decisions. Both the amount of resources available and the time distribution of when the funds become available are issues for Exploration Systems Development (ESD) as well as the Commercial Crew Program (CCP).

The President's annual CCP budget request vis-à-vis the appropriation is shown in Figure 2.

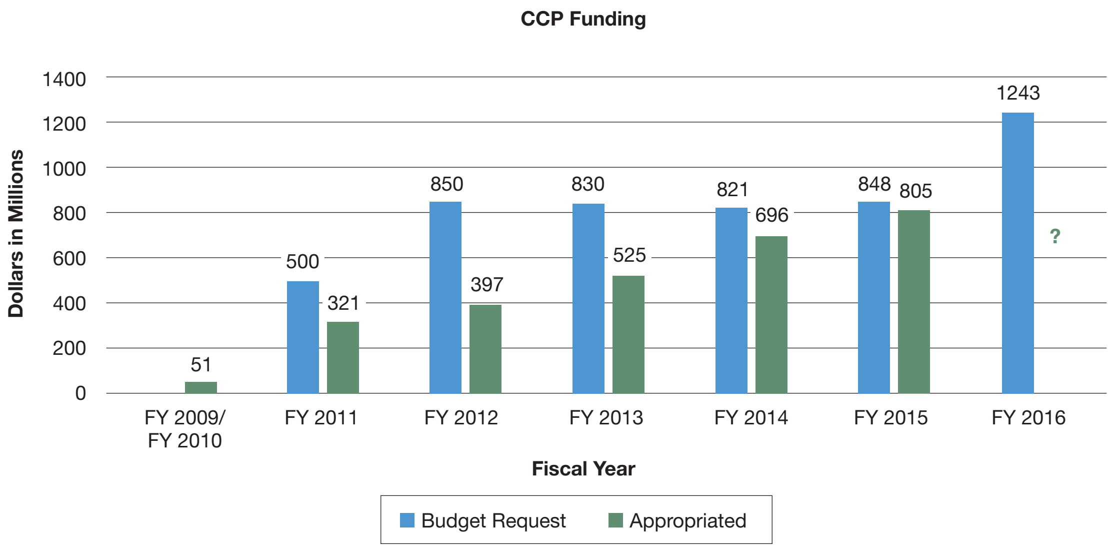

Figure 2. CCP Budget Requested and Appropriated, FY 2009–2016

The CCP was underfunded during the critical early years of development. Specifically, the Program received only 57 percent of the requested funding in fiscal year (FY) 2011 through FY 2013. This underfunding in the critical early system design years resulted in a design at Critical Design Review that was not as mature as it might have been. This has also added to the program management and safety challenges. Going forward, there is high risk that the program may not receive sufficient funding to execute the planned program. Careful attention and close cooperation among NASA, the White House, and the Congress is necessary to deliver safe and effective transportation to low-Earth orbit. Again, the ASAP strongly believes competition between two suppliers is essential to ensuring the best and safest design, given the fixed-price contracting strategy. It is concerning to note that in the chart above, the Agency is 3 months into FY 2016 and the budget for CCP is not known. This budget uncertainty increases the challenge of managing already complex programs.

ESD funding is presented in similar fashion in Figure 3. ESD has been resourced at a greater level than the President's Budget Request by an average of 10.5 percent during FY 2012 through FY 2015. However, the funding profile has been essentially flat. This distribution of resources reflects one more typically observed in "level-of-effort" programs rather than a budget constructed to achieve the needed design efforts of a major program's discrete and integrated requirements. In addition, funding is appropriated for individual elements rather than the program as a whole, which limits NASA's ability to more efficiently allocate resources to prudently address issues. As noted in the conclusion section of the ASAP's 2014 Annual Report, NASA's response has been to embrace "…a strategy of 'capabilities-based' investments. This strategy develops and matures many of the new technologies and methodologies required for the future but does not deliver an integrated capability. While this is an understandable pragmatic response to insufficient funding, this approach costs more and can negatively impact overall performance and safety in the long run." Careful attention and considerable program management skill will be required to ensure the resulting "Journey to Mars" system achieves the optimum balance between risk and reward.

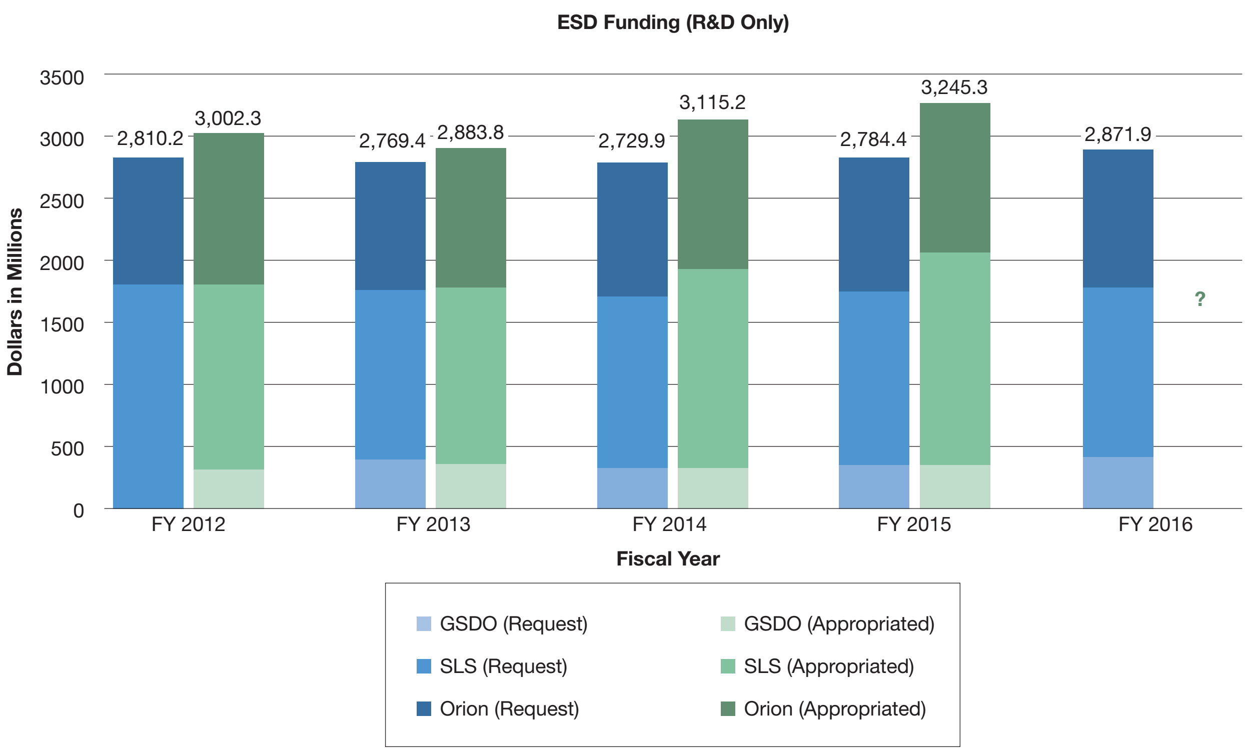

Figure 3. ESD Budget Requested and Appropriated, FY 2012–2016

IV. Accretion of Risk is Impacting Safety

A. Accretion of Risk—Overview

Over the past year, the Panel has noted a continuing and unacknowledged accretion of risk in space flight programs that we believe has the potential to significantly impact crew safety and the safe execution of human space missions. The Panel's concern is not the result of singular action but the accumulated impact of decisions made and risks assumed—either explicitly or tacitly, in small or large steps—that have mounted up and led to an apparent erosion of safety. While the ASAP does not assume that a challenging endeavor such as space exploration can be undertaken free of risk, we have consistently stated that, in a healthy, risk-management environment, risks should be deliberately and thoroughly vetted, balanced against the expected gain from taking the risk, and acknowledged candidly and with clear accountability and documentation.

While the programs appear to recognize and accept risk growth in many individual situations, we are not convinced that NASA recognizes or clearly communicates the aggregated impact of individually accepted component risks. Despite the ASAP's long-standing recommendation, NASA is not clearly and transparently communicating the recognition of the accreted risk, its impact to overall safety, and the rationale of why the increased risk is acceptable. This leaves the ASAP uncertain as to whether this accretion of risk is prudent or not. In some situations, NASA has characterized the changes as negligible and portrayed them as necessary and prudent actions that must be taken to maintain a schedule that appears to us to be an overly restrictive and internally imposed constraint.

We are concerned that without clearly defined acceptance of risk that takes into consideration and documents all alternatives and the potential consequences of the assumed risk, the likelihood of successful and safe execution of NASA's human space flight mission will be diminished. This situation can also become detrimental to sustaining a safety culture that encourages free and open dialog concerning risk among all Agency levels. In addition, it can unfavorably impact the perception of and confidence in NASA. The Panel has raised this issue of risk accretion and acceptance in previous Annual Reports but unfortunately has not noted improvement. In fact, the unacknowledged accumulation of risk appears to be increasing.

Subsequent sections of this Report will provide details pertaining to our specific concerns, but the kind of situations that have led to our disquiet include:

- The test program for components of Exploration Systems Development (ESD) appears to have gradually eroded since 2010. Among the multiple changes that have diminished the testing rigor are the decisions to reduce the scope of the Ascent Abort 2 (AA2) test and to delete pyrotechnic (pyro) shock/separation testing at the integrated system level.
- Late changes are being made to the Orion heat shield design with only one opportunity (Exploration Mission-1) to flight test the new design prior to the first crewed mission.
- Exploration Mission (EM)-2 is scheduled as the first crewed flight of the Space Launch System (SLS) and the first flight of the Orion environmental control and life support system

(ECLSS). This system will not have had an end-to-end flight test to build confidence that it will function safely during a cislunar mission where return to Earth could require up to as much as 11 days. This plan appears to incur an increased risk without a clearly articulated rationale.
- The SLS infrequent flight rate leads to higher risk due to mission operations team personnel loss and fading memories of lessons learned. EM-1 is scheduled to launch in mid-2018, and EM-2 is scheduled for launch between 2021 and 2023. NASA has told the ASAP that the intent is to launch once per year subsequent to EM-2, but the demand and schedule are vague.
- There has been growth over time in the maximum acceptable Loss of Crew (LOC) probabilities. This was discussed in the ASAP's 2014 Annual Report.
- While much of the accretion of risk we have seen is in ESD, the Commercial Crew Program (CCP) is subject to budget and schedule pressures that could lead to similar incremental risk acceptance decisions. As an artifact of the transition from Space Act Agreements to the Commercial Crew contractual arrangements, hazard reporting is behind for the CCP. There is a lack of design maturity at Critical Design Review (CDR); therefore, design is going forward without the benefit of the completed hazard analyses.
- Additionally, in the CCP, the lack of formality or "paperwork" aspects of design decisions and changes is a concern. There is danger that this will lead to an undesirable and unplanned or unrecognized increase in risk acceptance as schedule and budget pressures mount.

There are many pressures that lead to the assumption of risk: inadequate or less than optimally sequenced resources, desire to maintain a specified schedule, anxiety that not demonstrating sufficient progress will diminish program support, workload demands, and others. But while these are all legitimate weights on program execution—and all program managers must deal with similar pressures—the ASAP remains convinced that a primary contributing factor to our perceived accretion of risk is continued lack of clear, transparent, and definitive formal risk acceptance and accountability. By this we mean a decision process that addresses risk with:

- unambiguous definition of the rationale for accepting risk, including stating the benefit to be gained;
- comprehensive examination of *all* alternatives, including modifying priorities, adjusting schedules, and approaching the activity in an alternative manner;
- explicitly addressing and documenting the expected and potential consequences, including the aggregated risk in the larger context;
- transparent communication of the decision and reasoning among and between leadership and workforce; and
- formal accountability by the responsible authoritative individual with signed documentation of the rationale.

The ASAP has a long-standing recommendation, "Processes for Managing Risk with Clear Accountability" (see Appendix A), that remains open and has not been adequately addressed. We observe continued manifestations of risk accretion with little detectible movement in resolving our concern with risk acceptance, which causes us great concern. The ASAP believes that significant decisions need to be made by an individual who clearly and publicly accepts responsibility for the decision and the results it produces. When a person in an executive position is required to take accountability for risk acceptance, positive things happen. There is a higher-level review of other options and resources, outside of the program manager's control, that can sometimes be redirected to "buy down" the risk. Risk acceptance is clearly a significant decision; the ASAP is disappointed that NASA has not recognized this and undertaken the timely resolution of our recommendation, which has been standing since January 2014. We are concerned that the continued lack of clear responsibility for assumption of risk is a substantial contributor to the currently observed risk accretion.

B. Program Assessments

1. Exploration Systems Development

a. Test and Qualification for First Crewed Flight

(1) Introduction and Background: In reviewing the ESD programs, the Panel focused on the path to the first crewed flight on EM-2. More specifically, the Panel looked closely at the evolution of the Orion test and qualification plan, which comprises the major part of NASA's Orion certification for crewed missions. The Panel is also following the risk assessment for EM-2 that must balance competing interests in designing the mission profile. Other issues being watched closely are the recent decision to change the Orion heat shield design and the resolution of "zero fault tolerant" failure modes of certain components in the Orion Service Module (SM).

EM-1, planned for launch in the third quarter of 2018, is an extremely critical milestone in the development of the Orion/SLS system. It will be an uncrewed flight test that demonstrates for the first time the integrated operation of critical mission capabilities and events, including module separations, equipment deployments, environment validation, and integrated system performance. It will be the first flight test of the redesigned Orion heat

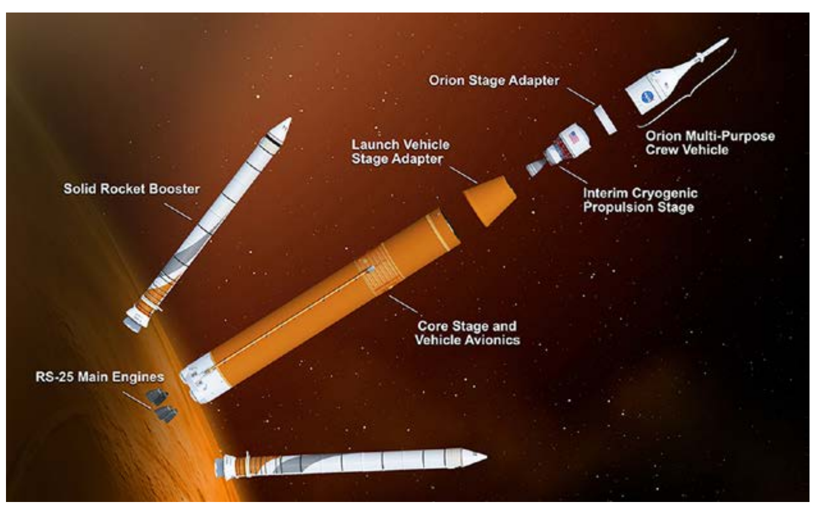

Figure 4. EM-1 SLS Configuration

shield, a functional Orion Service Module, and the SLS. The SLS configuration will pair the Core Stage and Boosters with the Interim Cryogenic Propulsion Stage (ICPS).

The ICPS performs the final stage of ascent—taking the Orion into low-Earth orbit (LEO) and performing the Trans-Lunar Injection (TLI) burn, sending Orion on its way to cislunar space. NASA's analysis of the ICPS vulnerability to micrometeoroid and orbital debris (MMOD) strikes while in LEO found this vulnerability to be the primary risk driver for Loss of Mission (LOM). Therefore, NASA is planning the TLI burn for the first orbit in LEO to meet the NASA minimum LOM requirement of 1 in 75. Several systems required for subsequent crew missions will not fly on EM-1; the most significant, from the Panel's perspective, is the ECLSS. Also, the Launch Abort System (LAS) motor will be inert on this flight. An overview of EM-1 is depicted in Figure 5.

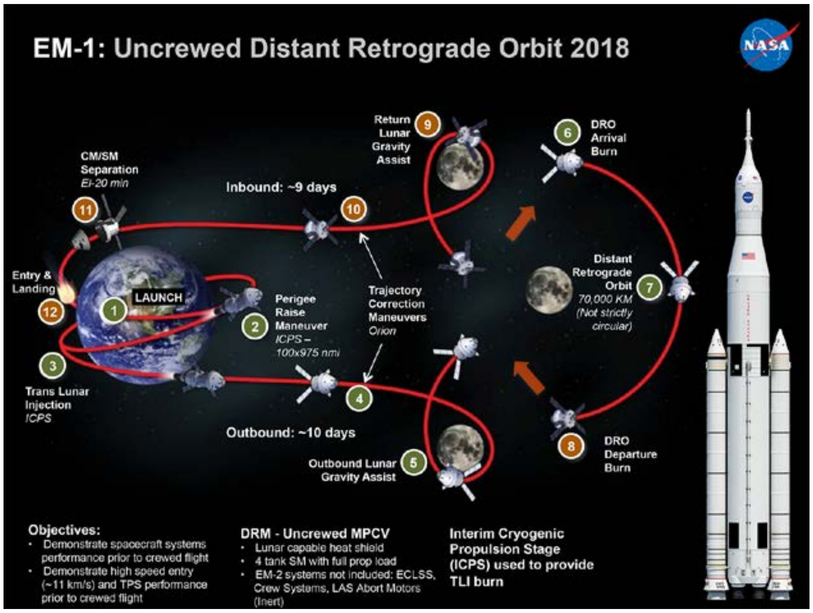

Figure 5. EM-1 Uncrewed Mission

EM-2, with a working launch date in the third quarter of 2021, is another critical milestone, as it is planned to be the first crewed flight. It will have a mission profile similar to EM-1 and will be the first flight and operational use of the ECLSS as well as other crew systems. It will also be the first flight of a fully operational LAS.

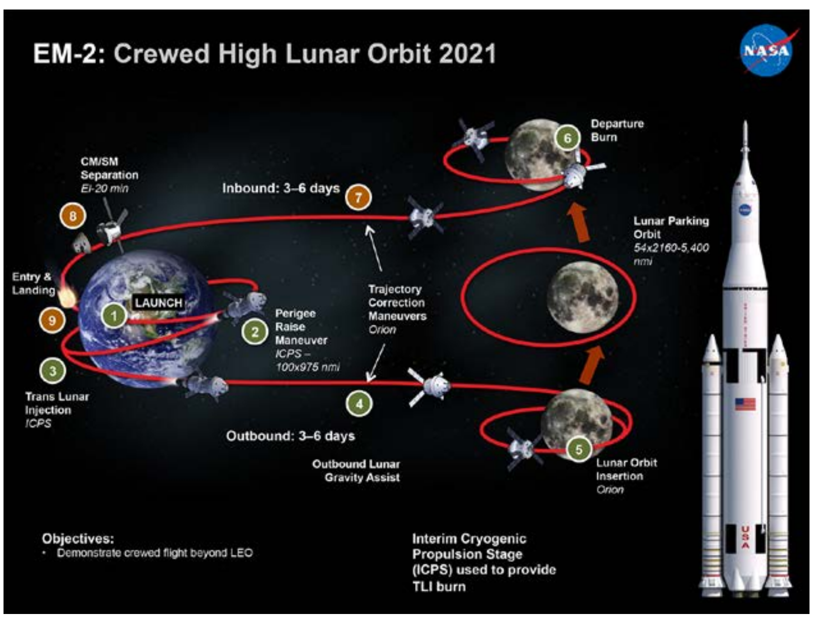

Figure 6. EM-2 Crewed Mission

The planned SLS configuration for EM-2 is the same as EM-1—utilizing the ICPS as the upper stage for ascent and subsequently for the perigee raise and TLI burns. Since the ICPS was not designed as a human-rated stage, it is not clear to the Panel whether NASA will require modifications to the ICPS for use on a crewed mission or accept the risk of flying "as is." To address the human-rating issue and the MMOD vulnerability of ICPS, NASA has been evaluating a change to the SLS configuration for EM-2—a newly designed Exploration Upper Stage (EUS). The EUS would have the potential advantage of being designed, built, tested, and certified for human missions from the very beginning. This change is contingent on funding.

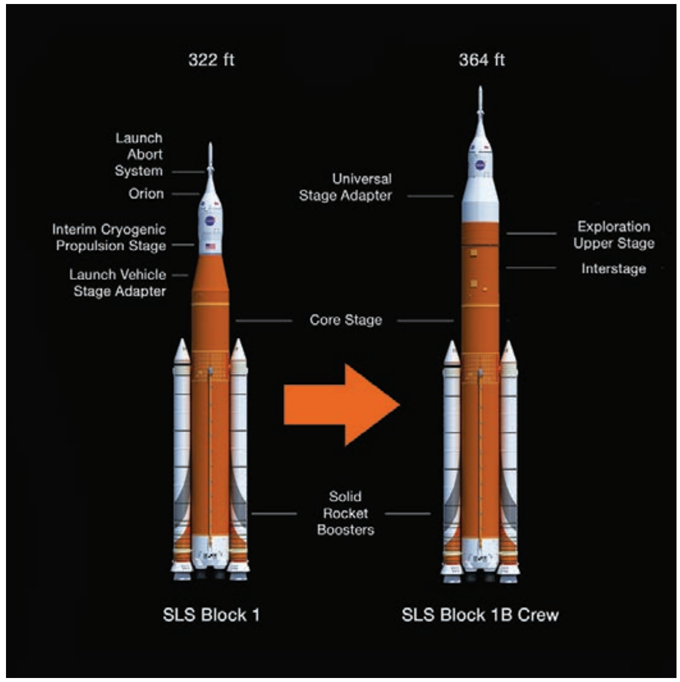

Figure 7. SLS Configurations

(2) Orion Test and Qualification Plan: Since 2010, numerous changes have been made to the Orion test and qualification plan. The first major change was made during the uncertainty of whether Orion would survive the Constellation Program cancellation. In an effort to reduce Orion's development cost, NASA decided to switch from a "dedicated qualification test article" approach to a "distributed qualification" approach, where the high-fidelity test articles will be used subsequently for flights, including the first crewed mission. This decision, while saving money, resulted in 18 issues (or gaps) in the test and qualification plan. One of the most significant gaps was the deletion of pyro shock/separation testing at the integrated system level.

While working to close the 18 issues, NASA also continued to modify the Orion test and qualification plan to deal with cost and schedule pressures. Two recent changes caught the attention of the Panel:

- the reduced fidelity of the AA2 test, and
- the use of module-level, direct field testing for vibro-acoustic qualification as opposed to integrated reverberant testing.

NASA informed the Panel that the change to AA2 was made to reduce cost. Also according to NASA, the change to vibro-acoustic qualification was made to reduce schedule risk for EM-1 and enable acceptance testing for subsequent missions to be performed at the Kennedy Space Center, saving time and money.

Taken individually, the decision to use a "boilerplate" or "non–flight-like" crew module instead of a high-fidelity crew module for AA2 is the most concerning to the Panel. AA2 is the only opportunity to flight test the LAS and its interactions with many other Orion systems in the challenging transonic flight environment. Qualification of the abort system ultimately relies on analytical models that are very complicated and have some degree of uncertainty. The new test plan misses a valuable opportunity to obtain a high-fidelity test point for analytical model validation as part of a complete "end-to-end" system test. The LAS is a primary safety feature that is allocated 95 percent reliability and will be flown on every mission for the next 40 years. It is the last hope for the crew if something goes wrong during the early phase of ascent.

Considering the test and qualification changes collectively, the Panel notes that the rationale used to justify one decision can be affected by subsequent decisions. For example, when NASA accepted the elimination of integrated pyro shock testing, part of the rationale presented to the Panel was that the "full vehicle would experience shock events at least once during flight prior to a crewed flight." However, the subsequent AA-2 decision eliminates a critical data point for the forward bay cover, which would have combined the actual acoustic and pyro shock environments of a transonic abort.

As mentioned above in Part IV.A, the Panel is also concerned that NASA has not fully assessed the aggregate increase in risk that is being accepted to hold schedule and content for EM-2. While each change to the test and qualification plan, considered individually, may appear to be a rational approach to dealing with cost and schedule issues, the cumulative effect is often not evaluated. Based on the Panel's review of the totality of the changes to the Orion test and qualification plan, the following recommendation has been made to NASA.

> *The ASAP strongly recommends that NASA evaluate the combined effects and aggregate risk increase associated with the multiple changes to the Orion test and qualification plan. The Panel especially recommends that NASA review decisions that were driven, in part, by a constraint to hold the EM-2 schedule and content for 2021. As part of the review, the Panel recommends that NASA fully assess the alternative of schedule relief and/or EM-2 content change as opposed to accepting the additional risk associated with the modified test/qualification.*

(3) EM-2 Upper Stage MMOD Risk/First Flight of ECLSS: The Panel is closely following the final decisions for EM-2 concerning the detailed mission profile and the SLS upper stage configuration. EM-2 will be the first flight of the Orion ECLSS, and there is a strong case for remaining in LEO until confidence is gained that the life support systems are performing properly. While in LEO, Orion can return to Earth in 1 to 2 hours via an emergency deorbit. However, once Orion reaches cislunar space, return to Earth is typically 3 to 6 days away and can be as much as 11 days away. While checking out the ECLSS systems in LEO, the upper stage of the SLS—the ICPS—will remain attached to Orion since it is needed to perform the TLI burn. This presents the EM-2 mission designers with a set of competing interests in determining how long Orion should remain in LEO before proceeding to cislunar space. Time spent in LEO to check out and gain confidence in the life support systems comes at the price of increased risk of an MMOD strike to ICPS causing LOM or worse. Using the EUS for EM-2 is one potential solution, but NASA does not currently have the funding to make that commitment. Adding MMOD shielding to ICPS is also a potential solution. However, the Panel notes that this dilemma is self-imposed by NASA's decision to fly to cislunar space on the first crewed mission without a prior test flight of the ECLSS. This decision reflects an aggressive development plan that takes the Exploration System from qualification testing to integrated human operations in cislunar space in just two missions.

(4) Orion Heat Shield: One of the most important lessons learned from the Exploration Flight Test-1 mission in December 2014 involved the Orion heat shield. While the heat shield performed well during the actual flight, NASA discovered two problems with the "monolithic honeycomb Avcoat" design that occurred during fabrication: cracks in gore seams and reduced acreage material strength (about 50 percent). Faced with more challenging entry environments on the EM missions (higher temperatures, heat flux, and heat load), NASA conducted a trade study in early 2015 to look at an alternative design. Subsequently, NASA made the decision to change to a "molded block Avcoat" heat shield. In NASA's assessment, the molded block Avcoat represented lower technical risk as well as schedule and cost advantages.

While NASA has had extensive experience using a block tile heat shield on the Space Shuttle, not all of that experience has been positive. The Panel was very interested in understanding NASA's approach to verification of the bond between the molded block tile and the substructure. NASA's strategy involves testing to determine maximum void size (and aggregate de-bond area) that can be tolerated as well as using non-destructive examination (NDE) techniques to determine the presence of such voids and de-bonds. There are also four areas of the heat shield that cannot be inspected by NDE. NASA's plan is to prove the molded blocks can tolerate a maximum de-bond in the uninspected area. The Panel will continue to monitor this issue.

Finally, NASA has not formally stated to the Panel whether or not a flight test of the Orion heat shield is required prior to the first crewed mission. Given current NASA plans, EM-1 is the only opportunity for such a test. The Panel notes that EM-1 is a very ambitious mission with many challenges. In our opinion, the test of the new Orion heat shield has become one of the most important mission objectives.

(5) Orion SM "Zero Fault Tolerant" Failure Modes: The Panel is also closely following the resolution of multiple failure modes in the Orion SM systems that are zero fault tolerant. Some of the failure modes could result in the loss of crew and vehicle. For example, the SM propellant storage and delivery system has six latch valves directly tied to the bulk propellant storage tanks. Each of these valves has a seal that is zero fault tolerant to leakage as well as a mini bellows that is also zero fault tolerant to leakage. Should any one of these valves develop a leak in either the seal or bellows, all of the SM oxidizer or fuel (depending on the specific valve) would leak out of the system. This would leave the Orion with no ability to control attitude or perform in-space maneuvers—a catastrophic failure. In the current design, the SM propulsion tanks cannot be isolated to minimize the effects of a leak. NASA has committed to making changes to address some of these failure modes (e.g., adding redundant seals to the latch valves) and is in the process of evaluating potential design changes to address others. The Panel will continue to follow the resolution of these issues for EM-2.

b. Program Schedule Impact on Safety Risk

Throughout this year, NASA briefed the ASAP on budget constraints that continue to pressure the ESD program schedule, especially the EM-2 launch in 2021. This has consistently remained a top ESD program risk. Another key factor pressuring schedules and program cost are technical issues, which naturally arise in any complex endeavor such as ESD. Both of these items, among others, can delay schedule and drive up costs, which exacerbate already constrained budgets. It is a circular consequence but is nonetheless the reality. In the case of human space flight, program management must balance cost, schedule, and performance to deliver the product with the highest quality (safety performance) while minimizing schedule delays and cost overruns. The ASAP is not concerned with programmatic risk unless safety tradeoffs are made to gain schedule or reduce costs. With its external stakeholders, primarily Congress, NASA executive management has committed to a 2023 EM-2 launch with a 70 percent schedule confidence level. However, NASA's internal direction to the programs is to work to a 2021 EM-2 launch date, which has a schedule confidence level close to zero at requested funding levels. NASA has briefed the ASAP on measures, previously listed above and in Part IV.A, that appear to be making safety trade-offs in order to maintain a 2021 EM-2 launch schedule. As such, the Panel's questions include: What is the compelling reason to adopt these measures to maintain a 2021 schedule that appears to be unrealistic by NASA's own analysis? What other options are available? What are the EM-2 schedule drivers? Why is it important to fly crew on EM-2? As the Panel understands it, the post-EM-2 ESD schedule is not specifically defined. Along NASA's Journey to Mars in the 2030s there are many technologies and systems (illustrated in Figure 8) that have yet to be matured, making this a vague driver at best.

In the nearer term, EM-1 and EM-2 missions will demonstrate program progress that can, in turn, invigorate public interest and improve program budgets. Whether the driver is to demonstrate ESD program results or to genuinely strive for Mars in the 2030s, safety performance must remain paramount and not be compromised. While the desire to fly crew on Orion as soon as possible is understandable, NASA is building a long-term exploration program, and adjustments to the near-term schedule or mission content that result in far safer systems can be an advantageous trade. If safety performance is to be maximized in a fixed-budget environment, does it make sense to hold to a strict schedule with predefined mission content? The NASA "can-do" attitude, while commendable, must be guarded against so as not to compromise safety in this case. Given a targeted milestone completion date, a program manager will diligently work to meet that and balance schedule, budget, and approach to achieving performance—safety performance in this case. It is vital to send the message to program managers that schedule and mission content are not absolute constraints. Rather, they are elements of the trade space in their decision-making process, especially in safety matters. Externally committing to a 2023 launch for EM-2 while making decisions based on a 2021 launch date is a risky situation, because safety could be unnecessarily compromised unless guiding safety principles are established and maintained. The Panel will be scrutinizing the need to maintain schedule and inquire about other available options as safety trade-offs are evaluated and as future program constraints may call for a means to preserve schedule and cost.

		MISSION					
	Demand Areas	ISS	Cis-lunar Short Stay (e.g., ARM)	Cis-lunar Long Stay	Cis-Mars Robotic	Orbital Proving Ground	Mars Operational
Working in Space and on Mars	In Situ Resource Utilization and Surface Power		Exploratory ISRU Regolith	Exploratory ISRU	Exploratory ISRU and Atmosphere	Exploratory ISRU	Operational ISRU and High Power
Working in Space and on Mars	Habitat and Mobility		Initial Short Duration	Long Duration		Resource Site Survey	Long Duration/ Range
Working in Space and on Mars	Human/Robotic and Autonomous Ops	System Testing	Crew-tended	Earth Supervised	Earth Monitored	Autonomous Rendezvous and Dock	Earth Monitored
Working in Space and on Mars	Exploration EVA	System Testing	Limited Duration	Full Duration	Full Duration	Full Duration	Frequent EVA
Staying Healthy	Crew Health	Long Duration	Short Duration	Long Duration	Dust Toxicity	Long Duration	Long Duration
Staying Healthy	Environmental Control and Life Support	Long Duration	Short Duration	Long Duration	Long Duration	Long Duration	Long Duration
Staying Healthy	Radiation Safety	Increased Understanding	Forecasting	Forecasting Shelter	Forecasting Shelter	Forecasting Shelter	Forecasting and Surface Enhanced
Transportation	Ascent from Planetary Surfaces				Sub-Scale MAV	Sub-Scale MAV	Human Scale MAV
Transportation	Entry, Descent, and Landing				Sub-Scale/Aero Capture	Sub-Scale/Aero Capture	Human Scale EDL
Transportation	In-space Power and Prop		Low Power	Low Power	Medium Power	Medium Power	High Power
Transportation	Beyond LEO: SLS and Orion		Initial Capability	Initial Capability	Full Capability	Full Capability	Full Capability
Transportation	Commercial Cargo and Crew	Cargo/Crew	Opportunity	Opportunity	Opportunity	Opportunity	Opportunity
Transportation	Communication and Navigation	RF	RF and Initial Optical	Optical	Deep Space Optical	Deep Space Optical	Deep Space Optical
		Earth Reliant	Proving Ground				Earth Independent

Figure 8. Technologies and Systems That Have Yet to Be Matured

c. Technical Integration Challenges

In the Exploration Program, significant risks can develop through the interface of the SLS, Orion, and Ground Systems Development and Operations elements, as well as the individual components of those top-level systems. This manifests itself in the risk of technical integration. Normally handled by one of the technical engineering Centers, NASA has chosen to use NASA Headquarters personnel to manage this process. This is, at the very least, outside of NASA's prior experience with programs as complex as ESD and therefore raises the specter of increased risk. The current mechanism selected to manage and track these challenges is called the "Cross Program Integration Team," and at this time, the effort appears to be progressing satisfactorily, although it is still early in the ESD program. Cross program risks are currently being identified and their mitigation is being tracked.

As the first flights approach, this task will inevitably become more complicated. It is not fully clear that NASA Headquarters—with its budget, Congressional relations, total Agency issues, and limited technical staff—will be able to handle the rapidly developing technical issues and subsystem-level ramifications that must be properly addressed. The Panel will continue to assess this situation in the future.

2. Commercial Crew Program

As we have highlighted in Part II, the ASAP has noted substantial improvement in openness and interaction with CCP management. Overall, the current Program Manager knows the Program's challenges, transparently acknowledges the Program's risks, and is actively working to retire or mitigate them. The Panel notes many positive aspects of the CCP execution. The Program Office and the commercial providers seem to be benefiting from open communications and data sharing. The CCP structure requires three engineering Centers to work together, which results in joint learning. The CCP is making excellent use of the assets, experience, and talents of the NASA Engineering and Safety Center. The Program is also leveraging its continuing engagement with Sierra Nevada and Blue Origin through the residual Space Act Agreement efforts. The Panel has noted the Program's positive exploitation of the experience gathered from the Cargo Resupply Services (CRS) program, including the failure analyses.

As noted elsewhere in this Report, one of the positive aspects of the CCP on which the Panel continues to place great importance is the benefit derived from having two very different providers. Not only do they bring the very vital advantages of competition and robustness of supplier redundancy, but also the two disparate approaches are already proving to provide innovative and cost effective design solutions. We are aware that there may be budgetary pressures to down select to one provider, and we strongly recommend against any such action.

In its review of the overall schedule, the Panel observes that both providers are in the midst of CDR activities. These reviews have shown that there has been substantial progress by the providers in design maturation and buildup of their infrastructure. Some initial testing is being accomplished, as depicted in Figures 9 and 10. However, although both providers are reported to be on track for crewed launches to the ISS in 2017, significant challenges remain.

Figure 9. Boeing CST-100 Structural Test Article Being Assembled at KSC

An area of specific and long-term interest to the ASAP is certification of the CCP vehicles for human space flight, and Panel members made a focused visit to the Program Office to gain a greater understanding of the plans and processes for certification and certification status. The Program has very well-defined and documented certification requirements and standards that both providers must satisfy for design, verification and validation

Figure 10. SpaceX Preparation for Pad Abort Test

of design execution, and Certification of Flight Readiness. Documentation to support certification is flowing from the providers to the Program Office. The CCP has some exceptionally qualified personnel working to review providers' approaches for meeting certification requirements and to resolve issues that arise with respect to proposals for alternate standards or risks associated with the approaches planned by the contractors. While there are several open issues, these are being worked rigorously and with appropriate acknowledgement of risk. The Program Office has actions in place to complete the necessary documentation submittals and approvals in early 2016. This is, however, behind relative to desired timelines for meeting any 2017 launch dates (shown in Figure 11), and there is a high likelihood of delays to the first test flights.

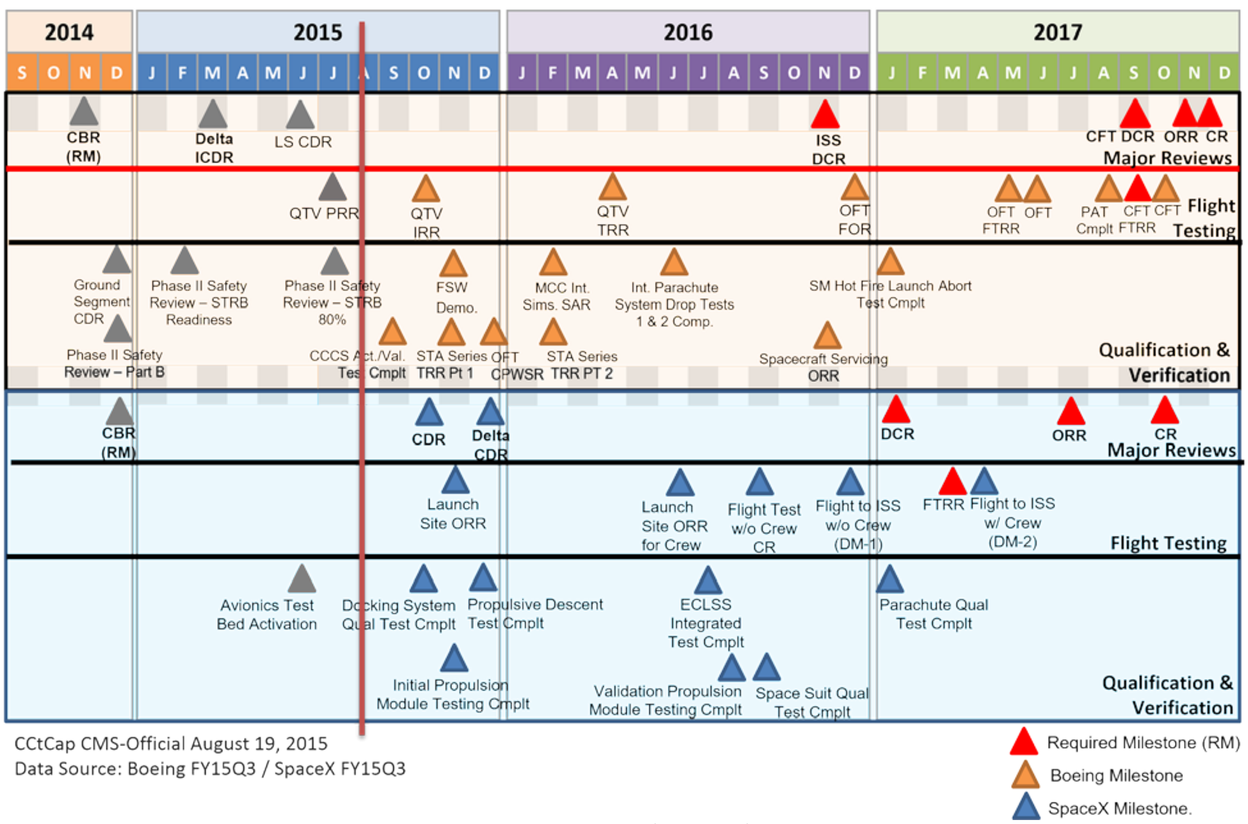

Figure 11. Commercial Crew Milestones

There are some areas where the ASAP sees significant challenges and cause for caution as the Program goes forward. The Program is experiencing the artifacts of the transition from a Space Act Agreement to a more formal contract. Along with the lag in certification planning, this is evident in the lack of design maturity at CDR and even more so in the maturity of hazard reports. While the hazard reports are now flowing, there is a significant backlog, and their quality and immaturity is putting a huge workload on the NASA Program Office. There is a temporal importance with respect to hazard analyses, and the ASAP has a concern that design is proceeding without the benefit of an information source that might provide an opportunity to mitigate potentially serious hazards that would be revealed with timely hazard analyses. This is also true for the adjudication of the requests for alternate standards in the certification process.

The ASAP also reviewed the Program's risk matrix and notes that the most extreme risk for both likelihood and severity is budget uncertainty. As we have noted in Part III, with the current appropriations outlook, the funding for the CCP may not be sufficient, and this could add pressure on the decision process and risk posture in the next year. The Panel's concern is that over time, schedule or budget pressure—or both—will lead the Program Office to accept more risk than desirable for crew and mission safety. The ASAP again emphatically cautions that the Program should not accept individual risks without regard for their accumulated impact. To her credit, the Program Manager was aware of this vulnerability. We also continue to advocate for a formal process and accountability for accepting those risks should they arise.

The ASAP observed another tendency or trend in working with the commercial providers—while the NASA Program Office could derive confidence from its observations that the providers were doing the "right thing" from engineering and safety standpoints, the formality or "paperwork" aspects were frequently missing or perfunctorily accomplished. The ASAP advises that the providers need to recognize that the discipline of doing and documenting the formal aspects benefits themselves as much or more than it benefits the Government.

The CCP has a requirement to achieve a LOC risk of no worse than 1 in 270 (1:270). Analysis of current designs indicates that they fall short of that limit. The primary risk contributor is MMOD damage. The strategy that is being taken to meet the LOC requirement is to back off to 1:200 for the spacecraft themselves, but to require that the design and vehicle capability be the sole means to achieve that level without consideration of operational adjustments. Any potential inspections or other operational workarounds will be put aside and left for later consideration. Both companies are now considering potential changes to their vehicles to address the MMOD risks. While there will always be risk from MMOD, NASA wants the providers to do as well as they can in using the spacecraft design to provide primary prevention before looking at other ways to improve safety through secondary preventive techniques such as inspection. There is some evidence that this strategy will have a positive result.

One more topic on which the ASAP and CCP management have engaged this past year concerns mishap response procedures. This is a complex issue—perhaps more so considering the role of the commercial providers. The Panel believes that these procedures should be thought through, documented, and in place well before any actual flights. This issue is discussed more fully in Part V.C.

Overall, while significant risks remain, the CCP appears to be on reasonably solid ground. The partnership between NASA and the commercial providers seems to be working and progress is being made. If properly funded, the Program should succeed in providing safe and effective transportation to low-Earth orbit.

3. International Space Station (ISS)

As noted in Part II of this report, the ISS continues to demonstrate exemplary performance with regard to maintaining planned operational tempo in spite of a string of logistical support interruptions due to three launch failures of Orbital ATK, SpaceX, and Russian cargo-bearing flights. These recent cargo launch failures reinforce the fact that space flight is hazardous and has tangible inherent risks that must be taken seriously and planned for in a thorough manner if probability of mission success is to be maximized. They also demonstrate the importance of having multiple launch methods for logistically supporting our crews on orbit.

NASA is participating with Orbital ATK, SpaceX, and Russia in a variety of ways to obtain insight into the causes of the mishaps that resulted in the failure of cargo to reach ISS. This fact-finding activity is ongoing and has required NASA to employ a variety of approaches to achieve the desired level of understanding. NASA is communicating with the various launch providers and is achieving the insight required to understand these events. In accordance with the terms of their launch license, Orbital ATK conducted an investigation, under FAA oversight, into the cause of the Orbital-3 failure. Orbital then provided the FAA with a report on their findings, which the FAA has accepted. Likewise, SpaceX recently completed an investigation into what happened on its CRS-7 mission and submitted its final report to the FAA in early December. The unprecedented loss of three different launch vehicle systems reinforces how difficult space flight is and underscores the importance of both having multiple launch systems from which to choose as well as the need to ensure that logistics planning is fault-tolerant.

Figure 12. Orbital-3 Launch Mishap

Figure 13. SpaceX CRS-7 Launch Mishap

As discussed in last year's report, the ISS is the largest object humans have ever placed in orbit. Unfortunately, one day it will also become the largest such object to fall from orbit, either at the end of its useful life, or with little notice if a catastrophic failure were to occur. Over the past 3 years, NASA and its international partners have made much progress in developing a plan for how to safely deorbit the ISS in either event. They are in the final stages of completing details of how the deorbit can be accomplished with minimum risk to people on the

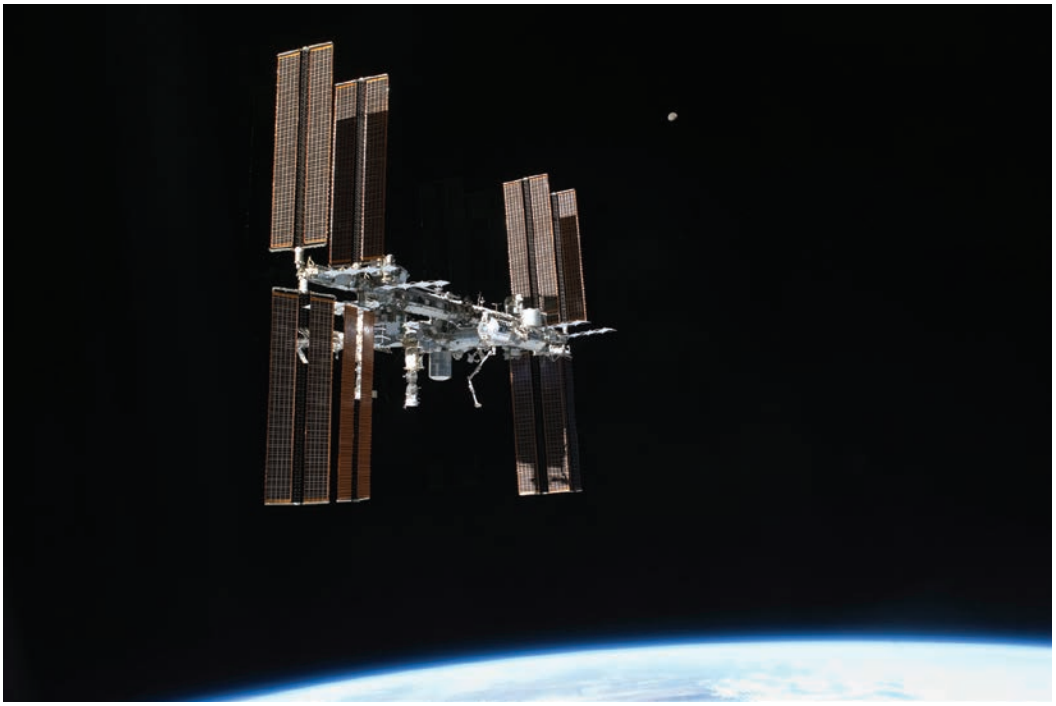

Figure 14. ISS—The Largest Object Placed in Orbit

ground. In the event of a serious failure, the possibility of an unplanned, emergency abandonment of the ISS does exist. For this reason, the Panel strongly encourages NASA and its international partners to complete all planning and preparation necessary to be ready on short notice for such an occurrence. Until such planning and preparation is completed, our recommendation from 2012, "International Space Station Deorbit Capability," remains open.

V. Other Topics

A. Journey to Mars Plan

Over the last few years, the ASAP has expressed its concern that NASA has not clearly formulated and communicated a long-term goal that would help to focus its efforts and inspire its workforce. In our 2014 Annual Report, we noted that, "The ASAP continues to believe that it is imperative that NASA unambiguously articulate a well-defined purpose, including a path toward the execution of that mission, the technologies that need to be developed and matured, and the resources needed to accomplish that mission." The Panel is pleased to see that, over the last 12 months, the situation has improved significantly. There can no longer be any doubt that NASA has selected Mars as its horizon goal. Almost every recent news release, press conference, or presentation by senior NASA managers and administrators makes mention of the "Journey to Mars." That statement of a definitive goal is a positive development, and we believe that it has had benefits in employee morale as well as support and engagement by the general public.

In October 2015, NASA published what it called "a detailed outline" of its next steps in getting to the Red Planet. Unfortunately, the level of detail in the report, *NASA's Journey to Mars: Pioneering the Next Steps in Space Exploration*, does not really validate whether NASA would be capable of achieving such an ambitious objective in a reasonable time period, with realistically attainable technologies, and with budgetary requirements that are consistent with the current economic environment. NASA describes its plan as consisting of three phases: Earth Reliant, Proving Ground, and Earth Independent. The Earth Reliant phase is focused on research being conducted onboard the International Space Station (ISS). It consists of missions lasting from 6 to 12 months, with a return time to Earth possible within hours. The Proving Ground phase involves learning how to conduct complex operations in a deep-space environment, primarily in cislunar space. It is expected to involve missions lasting from 1 to 12 months, with a return-to-Earth time measured in days. The Earth Independent phase is intended to enable human missions to the vicinity of Mars, including the Martian moons, and eventually the Martian surface. These missions are anticipated to last from 2 to 3 years, and will have Earth return times measured in months.

Although the document does identify a few specific technologies that will be needed to accomplish the overall mission, including Solar Electric Propulsion and a Deep Space Habitat, it lacks a top-level architecture and/or design reference mission. Without these elements, it will be difficult to properly scope and sequence the needed technology development efforts to ensure that they will be available at the appropriate time. When questioned about the lack of a specific mission plan, senior NASA leaders have replied that it is too early for such plans. They are reluctant to design vehicles or missions with today's technologies, since it is hoped that improvements can be made in the next 20 years that would radically change how such systems could be built. They may also be concerned that spelling out a particular plan for reaching Mars today would somehow subject it to criticism by future administrations. However, developing at least a preliminary reference mission could serve as a benchmark for what is possible today and could indicate where advancing the technological state-of-the-art would provide the most payoff in the future. Cost is also important. *NASA's Journey to Mars* report notes that, "While the Space Launch System (SLS) and Orion flight rates will ultimately be determined by available funding and mission requirements, NASA is working towards flying at least one crewed mission per year." It is not at all clear that one SLS flight per year would support the kind of launch campaign needed for a serious Mars exploration program. On the other hand, if the recommended program does require multiple, very expensive flights per year of the SLS, that should be acknowledged upfront.

The ASAP believes that a well-designed mission, with anticipated rewards that are expected to outweigh the risks, would go a long way toward gaining the needed support from future administrations, the Congress, and the general public. If not, then perhaps NASA should be working on a different mission, or at least using a different approach for the current mission.

NASA has recognized that it will be important to take advantage of international and commercial partnerships in its exploration activities. *NASA's Journey to Mars* report references the Global

Exploration Roadmap, which is a product of 12 space agencies committed to expanding human presence in space. The roadmap includes three different mission themes: exploration of a near-Earth asteroid, extended-duration crew missions, and humans to the lunar surface. It notes that "Many agencies consider human missions to the lunar surface as an essential step in preparation for human Mars missions." NASA has indicated its willingness to contribute to such a mission, but has ruled out taking a leadership role. So far, no other countries have stepped forward to take NASA's place. As a result, it is not clear that the international partners will have an opportunity to engage in the Proving Ground arena while NASA develops the systems and procedures needed to complete the much more difficult trip to Mars. It is also unclear how NASA will develop low-gravity surface experience and technology without lunar surface experience.

As an example of one of the potential unintended consequences of not announcing a specific reference mission and corresponding schedule to get to Mars, consider the discussions currently taking place concerning the ISS. Given NASA's existing budget, it appears that significant Proving Ground or Earth Independent activities would not be supportable until after the end of ISS operations, currently planned for 2024. Not having to pay for ISS operations presumably would free up several billion dollars per year that could then be devoted to activities in cislunar space and beyond. However, some NASA managers (as well as industry partners) have spoken publicly about the benefits of continuing to operate the ISS until 2028, or even later. While there may be benefits from such a plan, unless NASA were to be given a large increase in its appropriations, it is possible that continuing the ISS past 2024 may delay the Journey to Mars due to limited funding.

B. Aircraft Management Information System

The Panel has been tracking the funding for the NASA Aircraft Management Information System (NAMIS) for the past several years. The funding for this critical information management system has been inconsistent, with no assured stability in the past or anticipated in the near future. The Panel endorses a sustainable funding profile to prevent increased flight safety risks.

NAMIS is the program of record for tracking critical maintenance information on all NASA aircraft and is a crucial component to aviation safety. The system components include flight scheduling, flight data capture, maintenance (Organizational, Intermediate, and Depot level), aircraft configuration management, documentation, and logistics. The NASA Aircraft Management Division is also placing a high priority on incorporating Unmanned Aircraft Systems into NAMIS.

NAMIS system maintenance and upgrade requirements consistently outpace funded levels by about 31 percent annually and must rely on other less-than-dependable funding sources from year to year. The funding outlook through FY 2019 shows even greater shortfalls of up to 46 percent. The NAMIS system is crucial to NASA aircraft operations safety, and historical data demonstratively shows that the financial return on NAMIS justifies full funding. ASAP will continue to monitor this situation for future funding profiles and the means of this funding.

C. Human Space Flight Mishap Investigation Planning

A key part of any space development program is the planning for how to react in the event of a major malfunction or mishap. As noted above in Part IV.B.2, NASA's CCP is now developing formal plans for how it will respond if such an event occurs during the program. In addition to optimizing what can be learned by proper investigation of malfunctions or mishaps, this plan must comply with specific language in the NASA Authorization Act of 2005 concerning Human Space Flight Independent Investigations (see Appendix C). NASA has tentatively identified the entities that would investigate various types of mishaps during the five mission phases in Figure 15.

Mission Phase	Contractor Injury/Fatality or Property Damage (1)	NASA Injury/ Fatality or Property Damage (2)	Vehicle Damaged/ Flight Crew Recovered (4)	Vehicle Loss/ Flight Crew Recovered (3)	Loss of Flight Crew (3)	Public Injury/ Fatality or Property Damage (4)
Pre-Launch	Contractor	NASA	FAA/NTSB	Presidential Commission	Presidential Commission	FAA/NTSB
Ascent	N/A	NASA	FAA/NTSB	Presidential Commission	Presidential Commission	FAA/NTSB
On-Orbit	N/A	NASA	NASA	Presidential Commission	Presidential Commission	NASA
Descent and Landing	N/A	NASA	FAA/NTSB	Presidential Commission	Presidential Commission	FAA/NTSB
Post Landing	Contractor	NASA	FAA/NTSB	Presidential Commission	Presidential Commission	FAA/NTSB

Figure 15. Investigation Entities by Mission Phase for Various Types of Mishaps

It is noted that 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. This allocation is based directly on the language of the NASA 2005 Authorization Act, which would have been logical for ISS or Space Shuttle missions because they were reusable national assets. It would, however, appear excessive in some cases for commercially provided vehicles or other vehicles not planned for reuse. One example would be the sinking of a non-reusable vehicle after the flight crew had been safely recovered and were on their way home.

The following recommendation has been made to NASA.

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.

VI. Summary

Nine topic areas, highlighted in this report, are summarized in the table on the following page. They have been broken out to focus attention on individual topics that we feel are worthy of note.

Of the nine topic areas, two are rated as **red ■**, indicating they are longstanding and have not yet been adequately addressed. We listed these overarching, red-rated issues separately, because we believe that their resolution would significantly contribute to reducing the risk across a wide range of programs and activities. Had we made these red issues a component of the other items, such as those related specifically to Exploration Systems Development (ESD) and the Commercial Crew Program (CCP), it would have compelled us to rate ESD and CCP red and may have led to misinterpretation by the reader that the red rating of ESD and CCP was due to technical factors in these programs rather than to the overarching issues of inadequate funding and risk management practices. In this way, we are highlighting the high priority we place on addressing the red issues so that a significant cross-cutting benefit can be realized by a number of programs which otherwise would continue to be in a situation of preventable jeopardy.

The topics highlighted in **yellow ▲** are important issues or concerns that are either currently being addressed by NASA but are still unresolved, or are not currently being addressed by NASA. These issues will continue to be examined closely by the Panel.

One topic, the International Space Station (ISS), is indicated as **green ●**—a positive aspect that is being addressed by NASA, but continues to be followed. The ISS is the largest system humans have ever put into space, is complex, and has safely operated for over 15 years. It is being well managed, but the ASAP continues to monitor the ISS Program closely in light of the dangers associated with human space flight.

Topics	2015 Assessment
■ **Funding Adequacy and Profiles**	From 2012 through 2015, the CCP was not funded at the requested levels. Going forward, we are concerned that the CCP may not be sufficiently funded to execute the planned program and sustain competition, which we believe to be critical to both safety and success. The ESD funding levels have been flat—an approach that does not reflect the profile needed for a human space flight development program. Funding for the NASA Aircraft Management System has been erratic, with little likelihood of future stability. Sustainable funding is needed to prevent increased flight safety risks.
■ **Managing Risk with Clear Accountability and Formal Risk Acceptance**	We remain convinced that a primary contributing factor to our perceived accretion of risk is continued lack of clear, transparent, and definitive formal risk acceptance and accountability. We have had a long-standing recommendation on this topic that remains open and has not been adequately addressed.
▲ **ESD—Test and Qualification for First Crewed Flight**	Since 2010, numerous changes have been made to the Orion test and qualification plan for the first crewed flight. The Panel believes that the cumulative effect of these changes has significantly increased the risk that NASA will be accepting, primarily in the vibro-acoustic and pyro shock qualification. In addition, the Panel is very concerned with the decision to reduce the fidelity of the Ascent Abort 2 test. We are also closely following the Orion heat shield redesign and the Service Module failure-tolerance issues.
▲ **ESD—Program Schedule Impact on Safety**	Contrary to its own schedule analysis, NASA's internal direction to the ESD programs is to work to a 2021 Exploration Mission (EM)-2 launch date. NASA has briefed the Panel on measures that appear to be making safety trade-offs to maintain this schedule. Externally committing to a 2023 launch for EM-2 while internally making decisions based on a 2021 launch date is a risky situation, because safety could be unnecessarily compromised.
▲ **ESD—Technical Integration Challenges**	NASA's mechanism to manage technical integration challenges among the three ESD programs utilizes a coordinating systems engineering function at NASA Headquarters. While that appears to be working at the moment, as first flights approach, this activity will become far more complicated. It is not clear that NASA Headquarters, with limited engineering staff and the constant need to interact with external stakeholders, can continue to devote the necessary effort to the technical issues and subsystem-level effects.
▲ **Commercial Crew Program**	We have noted NASA's substantial improvement in openness and interaction with the Panel, and we have reviewed design, hazard reports, and certification processes. The Program Office is working all of these with the providers and managing risk. Open issues are being worked rigorously. However, the process is behind relative to desired timelines for meeting 2017 launch dates. Insufficient funding will put pressure on the risk posture.
● **International Space Station**	ISS continues to demonstrate exemplary performance despite three cargo-bearing launch mishaps within 1 year. NASA is participating with the cargo providers in a variety of ways to obtain insight into the causes of the mishaps. Over the past 3 years, NASA has made progress in developing a plan for how to safely deorbit the ISS and is in the final stages of completing the details. We strongly encourage NASA to complete all preparation necessary to be ready on short notice for an unplanned, emergency abandonment.
▲ **Journey to Mars Plan**	Over the past year, it has become clear that NASA has selected Mars as its horizon goal. However, its recently released plan, *NASA's Journey to Mars*, lacks a top-level architecture or design reference mission. We believe that without these elements, it will be difficult to scope and sequence the needed technology development efforts to ensure that they will be available at the appropriate time.
▲ **Human Space Flight Mishap Investigation Planning**	Under the NASA Authorization Act of 2005, a Presidential Commission investigation is required in all cases involving loss of flight crew as well as cases involving loss of vehicle, even if the flight crew is not injured. Such a Commission review appears excessive in some cases for commercially provided vehicles or other vehicles not planned for reuse. We have recommended that the Authorization language be reviewed with today's systems in mind.

  

Appendix A

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

2015 Recommendations

2015-05-01

Orion Risk Assessment: The ASAP strongly recommends that NASA evaluate the combined effects and aggregate risk increase associated with the multiple changes to the Orion test and qualification plan. The Panel especially recommends NASA review decisions that were driven, in part, by a constraint to hold the EM-2 schedule and content for 2021. As part of the review, the Panel recommends that NASA fully assess the alternative of schedule relief and/or EM-2 content change as opposed to accepting the additional risk associated with the modified test/qualification.

OPEN *This recommendation was presented and accepted by the Panel at the December 14, 2015, ASAP Public Teleconference Meeting. The ASAP did not receive a response from NASA before this report went to print.*

2015-05-02

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

OPEN *This recommendation was presented and accepted by the Panel at the December 14, 2015, ASAP Public Teleconference Meeting. The ASAP did not receive a response from NASA before this report went to print.*

Open Recommendations from Prior Years[1]

2014-01-01

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

> ● **OPEN** *The Office of the Chief Health and Medical Officer (OCHMO) briefed the Agency Program Management Council (PMC) on their implementation plan on November 18, 2015, and received concurrence on it. Once the associated decision memo has been signed, they will begin the process of putting the plan in place in the appropriate OCHMO NASA Procedural Requirement (NPR) document. Results to be presented at the 2016 First Quarterly Meeting.*

2014-01-02

Knowledge Capture and Lessons Learned: The ASAP strongly recommends a continuous and formal effort in knowledge capture and lessons learned that will make them highly visible and easily accessible. Modern tools exist to facilitate this and NASA should avail itself of them. NASA's Knowledge Management system should include risk-informed prioritization of lessons and a process to determine which lessons have generic (versus local or project-unique) potential. Further, it should be supplemented by formal incorporation into appropriate policies and technical standards of those lessons that are most important to safety and mission success. Rigor in this area is particularly critical as the experience in specific skills dissipates over time and as engineering talent is stretched across programs.

> ▲ **OPEN** *The Office of the NASA Chief Knowledge Officer (CKO) has continued activities designed to significantly increase Agency capabilities in capturing and sharing lessons learned/best practices through development of new Knowledge Services. The NASA CKO Office also significantly expanded the Agency's network of NASA and industry, Federal, national, and international knowledge practitioners, and expanded additional internal partnerships across NASA Centers, Mission Directorates, and functional Agency organizations as well as external partnerships with industry, academia, and other Government agencies. The office increased collaboration activities and problem-solving activities with NASA Center and Mission Directorate CKOs and other Agency points of contact on knowledge services activities aligned with the NASA Policy Directive (NPD) 7120.6 Knowledge Policy on Programs and Projects revision and improved the process for efficiently prioritizing and sharing lessons learned*

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1 *Note on color highlights:* ■ **Red** highlights what the ASAP considers to be a long-standing concern or an issue that has not yet been adequately addressed by NASA. ▲ **Yellow** highlights an important ASAP concern or issue, but one that is currently being addressed by NASA. ● **Green** indicates a positive aspect or a concern that is being adequately addressed by NASA but continues to be followed by the Panel.

and making formerly captured knowledge accessible and searchable for NASA. A full package summary of activities was presented to the ASAP in November 2015.

2014-AR-05

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

■ **OPEN** *The goal of the ASAP recommendation is clear, but numerous requirements and processes are affected by it. The issues that require clarification include treatment of aggregate risk, treatment of "As Safe As Reasonably Practicable," and fixing accountability in the context of a program or project being conducted by a multilevel technical hierarchy. In order to clarify these matters, an internal white paper was drafted, summarizing the clarifications that need to be implemented in the NASA documents affected by resolution of the single-signature issue. The draft white paper was recently circulated for limited internal review, and the Office of Safety and Mission Assurance is currently in the process of addressing the comments raised in that review.*

In the near term, a revised draft white paper will be circulated to a wider internal audience. Proposed modifications to NPR 8000.4 (Agency Risk Management Procedural Requirements) will then be prepared and circulated to those internal reviewers for comment. The Office of Safety and Mission Assurance is on track to complete modifications to this NASA directive by the end of March 2016.

Modifications of other affected NASA directives (e.g., NPD 8700.1) will be undertaken in the spring of 2016.

2012-01-02

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

● **OPEN** *Completion of timeline for the detailed planning and software for controlled ISS deorbit, in both the planned and unplanned conditions.*

2012-03-05

Five-Year Roadmap for Continuous Improvement of the Agency's Mishap Investigation Process: NASA should continue to report to the ASAP on the training of the MIT and the investigation Board Chairs in greater detail to include the method, consistency, and quality of training for MIT members and Board Chairs.

● **OPEN** *The NASA Safety Center (NSC) Mishap Investigation Support Office works in collaboration with the NASA Mishap Program Executive to monitor, maintain, and develop relevant mishap course materials for NASA personnel. Current budget schedules for development and maintenance of existing courses for out years to*

FY21 have been supplied to the ASAP. Additional resources for new course development are provided by Program Executive. The NASA Mishap Training regimen is robust and includes courses in NASA policy, procedure, root cause analysis, and human factors. Nine mishap courses for NASA personnel serving on mishap investigations have been identified and are available either online or in the classroom. Final development and completion of a new MIB Chair and Human Factors course is scheduled in FY16. The ASAP will receive a briefing by the NASA Institutional Safety and Mishap Program Executive at the 2016 First Quarterly Meeting. The Panel will consider closure of this item at that time, pending the presented road map lays out timely completion of the final two mishap courses—MIB Chair and Human Factors—that are in development.



Appendix B

Closure Rationale for Recommendations Closed in 2015

2012-03-01

Software Assurance and CMMI Requirements: All NASA internal safety-critical software development groups should achieve CMMI Level 3 (or an equivalent as established by external validation agent) by the end of FY14.

Closure Rationale

The ASAP received closure request from NASA stating that KSC completed their Capability Maturity Model Integration (CMMI) assessment, and they were awarded a Level 3 rating on Friday, June 26, 2015. This action closes this recommendation. The Panel would like to monitor NASA and Contractor's CMMI status as the certification is perishable—good for 3 years—and the Panel requests this data be provided to them annually.



Appendix C

NASA Authorization Act of 2005—Title VIII, Subtitle B—Human Space Flight Independent Investigation Commission

PUBLIC LAW 109—155—DECEMBER 30, 2005
(NASA Authorization Act of 2005)

Subtitle B—Human Space Flight Independent Investigation Commission

SEC. 821. DEFINITIONS.

For purposes of this subtitle—

(1) the term "Commission" means a Commission established under this title; and

(2) the term "incident" means either an accident or a deliberate act.

SEC. 822. ESTABLISHMENT OF COMMISSION.

(a) ESTABLISHMENT.—The President shall establish an independent, nonpartisan Commission within the executive branch to investigate any incident that results in the loss of—

(1) a Space Shuttle;

(2) the International Space Station or its operational viability;

(3) any other United States space vehicle carrying humans that is owned by the Federal Government or that is being used pursuant to a contract with the Federal Government; or

(4) a crew member or passenger of any space vehicle described in this subsection.

(b) DEADLINE FOR ESTABLISHMENT.—The President shall establish a Commission within 7 days after an incident specified in subsection (a).

SEC. 823. TASKS OF THE COMMISSION.

A Commission established pursuant to this subtitle shall, to the extent possible, undertake the following tasks:

(1) Investigate the incident.
(2) Determine the cause of the incident.
(3) Identify all contributing factors to the cause of the incident.
(4) Make recommendations for corrective actions.
(5) Provide any additional findings or recommendations deemed by the Commission to be important, whether or not they are related to the specific incident under investigation.
(6) Prepare a report to Congress, the President, and the public.

In Memoriam

Major General Claude M. Bolton, Jr., USAF (Ret.)
ASAP MEMBER 2012–2015

Aerospace Safety Advisory Panel

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NP-2015-10-2108-HQ