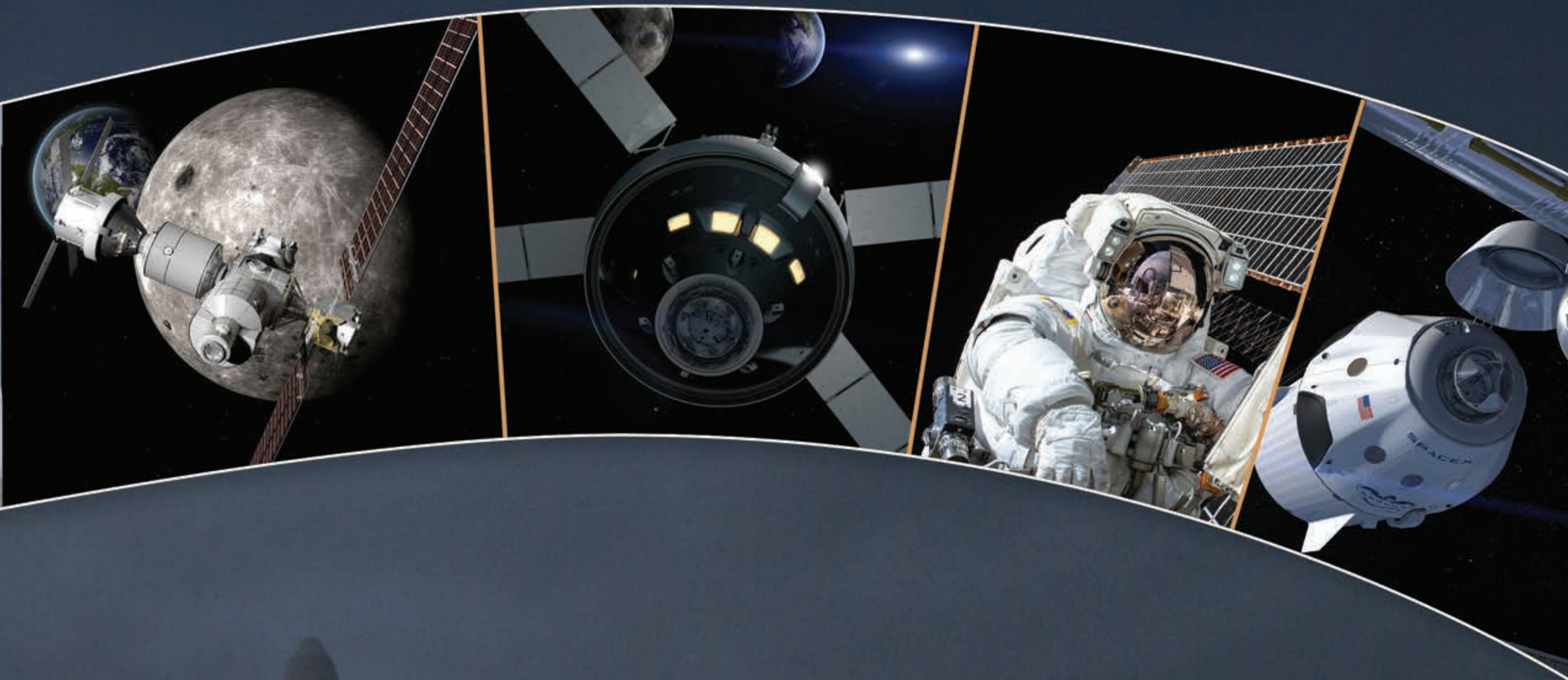


Aerospace Safety Advisory Panel

Annual Report for 2017

NASA AEROSPACE SAFETY ADVISORY PANEL

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

January 11, 2018

The Honorable Robert M. Lightfoot, Jr.
Acting Administrator
National Aeronautics and Space Administration
Washington, DC 20546

Dear Mr. Lightfoot:

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 2017 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 2017 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.

It is clear to the Panel that NASA is at a critical juncture in human space flight development. Both the Commercial Crew Program and the Exploration Systems Development are well beyond paper design with hardware being produced, testing underway, and first flights—uncrewed test flights followed by crewed test flights—on the horizon. This is a time when it is important to retain focus on program details; to maintain a sense of urgency while not giving in to schedule pressure; and to continue with program plans without neglecting, shortchanging, or deleting planned content. Important decisions are facing NASA leadership in certifying these platforms for human space flight that should be based on a strong foundation of test and engineering data.

The ASAP reiterates once again the need for constancy of purpose as NASA is on the verge of realizing the results of years of work and extensive resource investment in these programs. This includes making sure that the appropriate resources are provided to complete the job. We continue to strongly caution that any wavering in commitment negatively impacts cost, schedule, performance, workforce morale, process discipline, and—most importantly—safety.

The Panel believes that NASA is addressing safety properly, but space can be a decidedly hostile environment and human space flight is inherently risky. There is no excuse for negligence in the safety arena, but it is impossible to control, eliminate, or mitigate every risk. We particularly note that potential for damage from micrometeoroids and orbital debris has become recognized as a major issue in every program. The United States government should seriously consider expanding its efforts to lead in developing international strategies to reduce debris generation and the hazards posed by existing debris.

Recognizing that space flight holds inherent hazards, there is always a probability of mishaps needing rigorous and disciplined investigation to avoid future incidents and to return to flight as safely and as soon as possible. We believe it is important to have mechanisms and procedures in place before a mishap event occurs to enable expeditious and effective investigation. To that end, we propose a change to the language in the NASA Authorization Act of 2005 that prescribes a Presidential Commission for Human Space Flight Independent Investigations.

I submit the ASAP Annual Report for 2017 with respect and appreciation.

Sincerely,

Patricia Sanders

Dr. Patricia Sanders
Chair, Aerospace Safety Advisory Panel

Enclosure

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

January 11, 2018

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

Dear Mr. President:

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 2017 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 2017 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.

It is clear to the Panel that NASA is at a critical juncture in human space flight development. Both the Commercial Crew Program and the Exploration Systems Development are well beyond paper design with hardware being produced, testing underway, and first flights—uncrewed test flights followed by crewed test flights—on the horizon. This is a time when it is important to retain focus on program details; to maintain a sense of urgency while not giving in to schedule pressure; and to continue with program plans without neglecting, shortchanging, or deleting planned content. Important decisions are facing NASA leadership in certifying these platforms for human space flight that should be based on a strong foundation of test and engineering data.

The ASAP reiterates once again the need for constancy of purpose as NASA is on the verge of realizing the results of years of work and extensive resource investment in these programs. This includes making sure that the appropriate resources are provided to complete the job. We continue to strongly caution that any wavering in commitment negatively impacts cost, schedule, performance, workforce morale, process discipline, and—most importantly—safety.

The Panel believes that NASA is addressing safety properly, but space can be a decidedly hostile environment and human space flight is inherently risky. There is no excuse for negligence in the safety arena, but it is impossible to control, eliminate, or mitigate every risk. We particularly note that potential for damage from micrometeoroids and orbital debris has become recognized as a major issue in every program. The United States government should seriously consider expanding its efforts to lead in developing international strategies to reduce debris generation and the hazards posed by existing debris.

Recognizing that space flight holds inherent hazards, there is always a probability of mishaps needing rigorous and disciplined investigation to avoid future incidents and to return to flight as safely and as soon as possible. We believe it is important to have mechanisms and procedures in place before a mishap event occurs to enable expeditious and effective investigation. To that end, we propose a change to the language in the NASA Authorization Act of 2005 that prescribes a Presidential Commission for Human Space Flight Independent Investigations.

I submit the ASAP Annual Report for 2017 with respect and appreciation.

Sincerely,

Patricia Sanders

Dr. Patricia Sanders
Chair, Aerospace Safety Advisory Panel

Enclosure

NASA AEROSPACE SAFETY ADVISORY PANEL

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

January 11, 2018

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

Dear Mr. Speaker:

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 2017 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 2017 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.

It is clear to the Panel that NASA is at a critical juncture in human space flight development. Both the Commercial Crew Program and the Exploration Systems Development are well beyond paper design with hardware being produced, testing underway, and first flights—uncrewed test flights followed by crewed test flights—on the horizon. This is a time when it is important to retain focus on program details; to maintain a sense of urgency while not giving in to schedule pressure; and to continue with program plans without neglecting, shortchanging, or deleting planned content. Important decisions are facing NASA leadership in certifying these platforms for human space flight that should be based on a strong foundation of test and engineering data.

The ASAP reiterates once again the need for constancy of purpose as NASA is on the verge of realizing the results of years of work and extensive resource investment in these programs. This includes making sure that the appropriate resources are provided to complete the job. We continue to strongly caution that any wavering in commitment negatively impacts cost, schedule, performance, workforce morale, process discipline, and—most importantly—safety.

The Panel believes that NASA is addressing safety properly, but space can be a decidedly hostile environment and human space flight is inherently risky. There is no excuse for negligence in the safety arena, but it is impossible to control, eliminate, or mitigate every risk. We particularly note that potential for damage from micrometeoroids and orbital debris has become recognized as a major issue in every program. The United States government should seriously consider expanding its efforts to lead in developing international strategies to reduce debris generation and the hazards posed by existing debris.

Recognizing that space flight holds inherent hazards, there is always a probability of mishaps needing rigorous and disciplined investigation to avoid future incidents and to return to flight as safely and as soon as possible. We believe it is important to have mechanisms and procedures in place before a mishap event occurs to enable expeditious and effective investigation. To that end, we propose a change to the language in the NASA Authorization Act of 2005 that prescribes a Presidential Commission for Human Space Flight Independent Investigations.

I submit the ASAP Annual Report for 2017 with respect and appreciation.

Sincerely,

Dr. Patricia Sanders
Chair, Aerospace Safety Advisory Panel

Enclosure

Contents

CD Table of Contents

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 B, and the full text of the recommendation submitted to the Administrator during 2017 is included as Attachment 2 on the CD. 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

A. Aerospace Safety Advisory Panel 2017 Activities and Overall Observations

During 2017, the Aerospace Safety Advisory Panel (ASAP) conducted quarterly meetings hosted by Kennedy Space Center (KSC), Marshall Space Flight Center, NASA Headquarters, and Johnson Space Center (JSC). ASAP members also made insight visits to Glenn Research Center, Langley Research Center, and Jet Propulsion Laboratory, as well as insight visits to the commercial space facilities of Boeing, SpaceX, Lockheed Martin, United Launch Alliance, and Sierra Nevada. We held focused reviews—in-depth dialogues—with NASA engineers, safety personnel, and other relevant working-level staff addressing NASA aircraft operations and some specific aspects of the Commercial Crew Program (CCP). Two members participated in the Inter-center Aircraft Operations Panel (IAOP). The ASAP and the NASA Advisory Council continued their cross-coordination efforts and participation in each other's respective meetings.

We commend the affected Centers—particularly JSC and KSC, as well as the Michoud Assembly Facility—and the NASA workforce on their resilience and dedication in the face of Hurricanes Harvey and Irma and the tornado in Mississippi. While they were fortunate in not bearing as much of the storms' brunt as could be feared, it is a credit to the workforce, to excellent planning, and to some well-placed facility investments that the crucial missions and critical programs were uninterrupted by the events and no casualties were experienced. Still, damages were sustained that require restoration resources.

The assessments drawn from this year's activities will be provided in the following sections of this report, but we have some overall observations. It is clear to the Panel that NASA is at a critical juncture in the development of human space flight programs. Both the CCP and the Exploration Systems Development (ESD) are well beyond paper design and are at the stage where hardware is being produced, testing is underway, and first flights—uncrewed test flights followed by crewed test flights—are on the horizon. This is a time when it is important to retain focus on program details; to maintain a sense of urgency while not giving in to schedule pressure; and to continue with program plans without neglecting, shortchanging, or deleting planned content. To date, the ASAP has been pleased to note that there is no indication across NASA that schedule pressures are driving decisions that will adversely impact safety. Important decisions are facing NASA leadership in certifying these platforms for human space flight. These decisions will necessitate careful weighing of all the technical and operational aspects of the risk-benefit trades. It is important that the leadership base its decision-making process on a strong foundation of test and engineering data.

The ASAP reiterates once again the need for constancy of purpose, as NASA is on the verge of realizing the results of years of work and extensive resource investment in these programs. This includes making sure that the appropriate resources are provided to complete the job. We continue to strongly caution that any wavering in commitment negatively impacts cost, schedule, performance, workforce morale, process discipline, and—most importantly—safety. Also, we continue to be concerned with the pressure induced by the lack of budget certainty due to the ongoing use of continuing resolutions (CRs). The budget uncertainties associated with partial year CRs adds complexity to program management and inefficiency to execution. This detracts from maintaining the requisite focus on safety and mission assurance.

NASA Continuing Resolution (CR) History—Fiscal Year (FY) 2008–2018 (as of 12/26/2017)

	CR-1	CR-2	CR-3	CR-4	CR-5	CR-6	CR-7	CR-8	Final Appropri-ations	Date Enacted	Months Under CR
FY 2008	PL 110-92	PL 110-116	PL 110-137	PL 110-149					PL 110-161	12/26/07	3
FY 2009	PL 110-329	PL 111-6							PL 111-8	03/11/09	6
FY 2010	PL 111-68	PL 111-88							PL 111-117	12/16/09	3
FY 2011	PL 111-242	PL 111-290	PL 111-317	PL 111-322	PL 112-4	PL 112-6	PL 112-8	PL 112-10	PL 112-10	04/15/11	12
FY 2012	PL 112-33	PL 112-36	PL 112-55	PL 112-67	PL 112-68				PL 112-55	11/18/11	2
FY 2013	PL 112-75								PL 113-6	03/26/13	6
FY 2014	PL 113-44	PL 113-67	PL 113-73						PL 113-76	01/17/14	4
FY 2015	PL 113-164	PL 113-202	PL 113-203						PL 113-235	12/16/14	3
FY 2016	PL 114-53	PL 114-96	PL 114-100						PL 114-113	12/18/15	3
FY 2017	PL 114-223	PL 114-254	PL 115-30						PL 115-31	05/05/17	7
FY 2018	PL 115-56	PL 115-90	PL 115-96						TBD	TBD	TBD

FIGURE 1. The history of CR usage shows constant budget uncertainty over many years.

B. Micrometeoroids and Orbital Debris

The Panel believes that NASA is addressing safety properly, but human space flight is inherently risky. Space can be a decidedly hostile environment, and while there is no excuse for negligence in the safety arena, it is impossible to control, eliminate, or mitigate every risk. For example, we note that potential for damage from micrometeoroids and orbital debris (MMOD) has become recognized as a major issue in every program. In fact, damage from MMOD is the dominant contributor to the calculations of loss-of-crew (LOC) predictions for both commercial crew vehicles as well as Orion, and to two of the top three safety risks for the International Space Station (ISS).

Given the increased congestion in orbit and the recent announcement of plans to launch many mega-constellations in low-Earth orbit (LEO), with hundreds or even thousands of satellites, the U.S. government should seriously consider implementing significant improvements for Space Situational Awareness analyses and the provision of Space Traffic Management services, as well as expand its efforts in developing international strategies to reduce orbital debris generation in the future. This topic was addressed in the 2010 National Space Policy and has only increased in criticality since then. When appropriate, U.S. Strategic Command (STRATCOM) contacts space operators from over 50 countries and provides collision warnings when it determines that a conjunction of two space objects is possible. Meanwhile, NASA conducts its own collision analysis for the satellites for which it is responsible—using information provided by STRATCOM—at the Conjunction Assessment Risk Analysis Center at Goddard Space Flight Center. Because this is a critical safety issue that involves multiple departments and agencies—as well as all countries with space assets—it would appear to be a very worthwhile issue for the U.S. to take a leadership role and for the National Space Council to address. We believe that the Council should assign a lead Agency in the U.S. to spearhead and coordinate efforts to prevent the generation of new debris and reduce the hazards posed by existing debris.

C. Mishap Investigations

Recognizing that space flight holds inherent hazards, there is always a probability of mishaps. When mishaps do occur, they will need rigorous and disciplined investigation to learn what can be done better to avoid future incidents, maximize learning, and to return to flight as safely and as soon as possible. The ASAP believes that it is important to have mechanisms and procedures in place, as NASA currently has, before a mishap event occurs to enable expeditious and effective investigation that leads to corrective action. In December 2015, we recommended that the language in the NASA Authorization Act of 2005—requiring a Presidential Commission for Human Space Flight Independent Investigations—be reviewed and revised considering today's systems and environment. This recommendation remains open. We have several concerns with the current language:

- The process prescribed in the NASA Authorization Act of 2005 has the potential to slow the initiation of mishap investigations, which impacts the effectiveness of mishap investigation actions.

- The Commission—as defined in the language of the Act—would be composed of people who are not required to have investigative experience or experience relative to human space flight. A newly formed Presidential Commission may require a learning curve that further extends the investigation timeframe or degrades its credibility. It is clear to us that Congress intends to demand independent investigations, i.e., investigations that are free from any perceived NASA-directed influence. This does not mean that NASA should relinquish substantive responsibility related to investigation of its own human space flight mishaps. NASA will ultimately be the entity that must learn from the results of the investigation, decide on whether to accept the investigation results, and determine what corrective actions to take. It also does not mean that government personnel or contractors with relevant knowledge and expertise should be prohibited from participating in an appropriate role.

- The current requirement only applies to Government missions which would result in different investigation regimes, depending on the type of flight being conducted. We recognize that up until present day, human space flight in this country has primarily been under the Government's purview. However, soon private organizations, acting on behalf of their own pursuits, will also be engaging in sending humans into space. Changes to the law should establish a framework that reflects these changing times.

The ASAP believes that the establishment of a Presidential Commission should be discretionary and that, regardless of the composition of the independent body conducting the investigation, NASA should not be precluded from conducting parallel investigations, as defined in NASA regulations. We offer a possible alternative framework for investigations. The National Transportation Safety Board (NTSB) should lead the investigation for any commercial space mishaps that occur on non-Government missions. However, for mishaps involving loss of life or high value assets where NASA has authorized the mission, is responsible for the rules under which the mission was conducted, and accepted the risk—we recommend using an independent, standing mishap investigation body based on the existing Mishap Interagency Investigation Board (MIIB) model. We recommend this approach based on the mission owner, not necessarily the hardware provider, and regardless of the mission phase in which the mishap occurs. We propose that:

- The current inter-agency MIIB composition should be expanded to include, at least, a standing member from the NTSB and the Federal Aviation Administration (FAA). Standing members are important to the timeliness of a competent investigation process. Inclusion of the NTSB and the FAA, especially the NTSB, would enable those organizations to gain expertise in space-related investigations, which could increasingly be needed in the commercial sector.

- The Chair of any specific investigation could be selected by the President, Congress, or members of the MIIB, as deemed necessary. In any case, MIIB standing members could designate an Interim Chair to facilitate timely investigation startup.

- The expanded MIIB's independence should be maintained.

D. Future Work

In the coming year, the ASAP plans to spend focused effort on the CCP human certification efforts, looking closely at the progress of both commercial providers. We will also be looking attentively at ESD as that program prepares for the Exploration Mission (EM)-1 test flight.

Another planned focus area for 2018 is the safety culture status within NASA. Throughout 2017, in our discussions with NASA, we have noted some indicators that warrant a closer look. For example: Are the safety-related NASA Procedural Requirements fully adopted and enforced? Are safety practices truly "owned" by the workforce, or is there a "check the box" mentality in some areas? Are mishap investigations and corrective actions addressing true root cause, as opposed to proximate cause? Is the Office of Safety and Mission Assurance Technical Authority (TA) function sufficiently robust and fully performing in an independent manner? Is the NASA Safety Center living up to expectations? At this point, the ASAP has no clear and compelling evidence related to an overarching concern with NASA's safety culture, but this is an area that will garner our attention in 2018.

The ASAP reviewed some aspects of aircraft operations this past year, but our plan of work in 2018 will include more emphasis on aircraft operations safety, unmanned aerial systems safety, and NASA's new aircraft technology development.

Looking beyond the near-term challenges, the ASAP sees a window of opportunity for how the Nation views its future in space. NASA's development of the Space Launch System (SLS) and Orion will provide a heavy-lift, deep-space exploration capability not seen since Apollo. Meanwhile, the ISS has not only served as an on-orbit laboratory to study technology, operations, and the impacts of long-duration spaceflight on the human body; it has also allowed us to gain valuable experience using international partnerships in the pursuit of challenging scientific endeavors. The Deep Space Gateway (DSG) concept provides an important next step and could be a flexible and critical enabler for human exploration beyond LEO. At the same time, we may be finally reaching a tipping point regarding commercial space capabilities. There is a range of U.S. and international commercial systems either already flying or currently under development for suborbital space tourism, cargo delivery, crew transportation, commercial space stations, satellite servicing, lunar landers and rovers, asteroid mining, and even human missions to Mars. This presents a real potential for public-private partnerships that could benefit both government and industry as well as international relations.

With this rather broad and forward-looking vision, the U.S. may have an opportunity to transition to an "all-of-the-above" approach for space, rather than having NASA focus on a specific program or a single destination. Such an approach would involve joining forces with industry and the international community to a much greater extent and could enable the growth of a true space economy. But it will also bring greater complications and challenges for risk management, mission assurance, and the safety-benefit trade-off balance. It will also bring a unique opportunity for NASA to develop safety processes and mechanisms for the future as they guide and learn from new partners. As NASA navigates its future through this evolving environment, the ASAP envisions significant engagement in understanding and advising on those challenges that come with new ways of doing business and approaching shared safety responsibilities.

II. Exploration Systems Development

A. Exploration Mission-1 Crewed Mission Feasibility Study

At the request of the new Administration, NASA was asked to assess the feasibility of flying crew on EM-1, the first flight of the SLS rocket with the Orion Capsule. Redefining EM-1 as a crewed mission, while at the same time maintaining a reasonable risk posture, required examination of the hardware development schedule and the validation and verification testing required to assure crew safety.

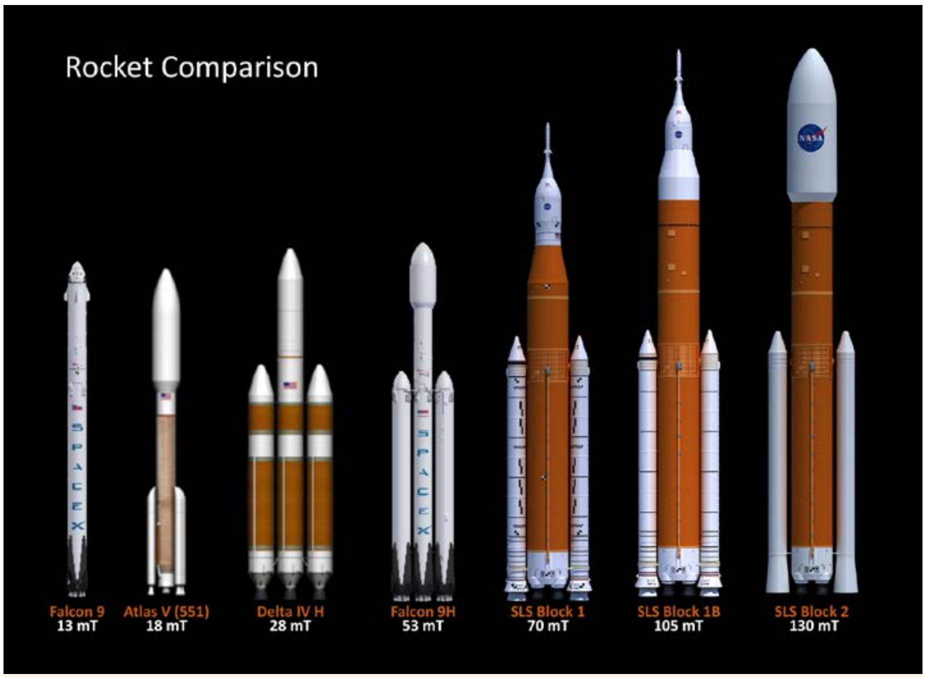


FIGURE 2. Comparison above illustrates significant size of ESD rockets. Hardware of this scale is always a technical and safety challenge.

NASA concluded that it would be feasible to move the crewed flight forward to EM-1; however, to do so would require a substantial immediate increase in resources in addition to increasing crew risk. An example of increased crew risk would be the lack of appropriate testing for the Orion heat shield. EM-1 is the first opportunity to perform a rigorous flight test of the Orion heat shield that protects the crew from the atmospheric heating during reentry. Moving crew to EM-1 exposes them to increased risk should the heat shield fail on its first trial. Additional concern for crew safety arises from the maturity level of the Environmental Control and Life Support System (ECLSS) design. EM-1 as an uncrewed mission does not currently contain an ECLSS suite. Consequently, the ECLSS development would need to be accelerated, potentially leading to less rigorous testing.

In summary, NASA found that while flying crew on EM-1 was technically feasible, it would add significant crew safety risk and demand considerable additional resources that could not be guaranteed. The ASAP concurred with that finding.

B. Safety Benefits Resulting from the Study

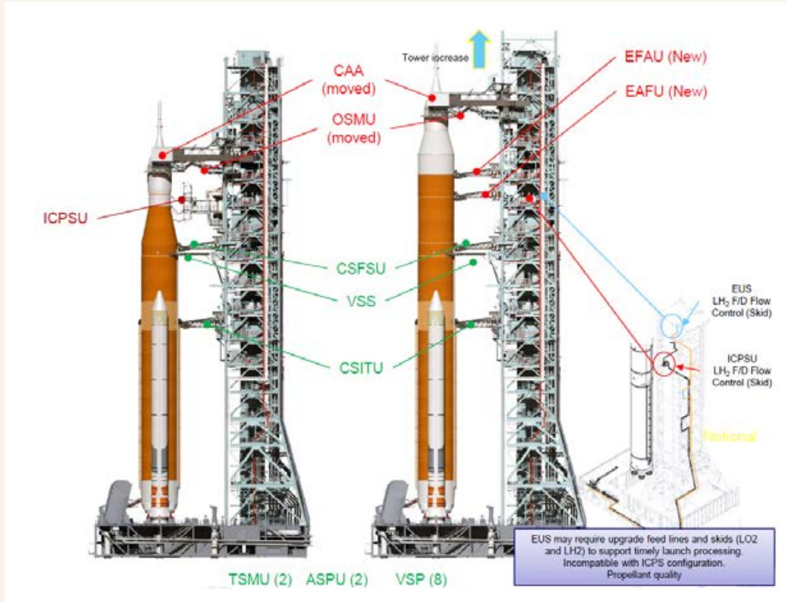


FIGURE 3. Modification of MLP: 13 meters = Big Changes. The items shown in red are major pieces of the MLP that must be removed, altered, or added.

Conducting the study did reveal new information and opportunities to reduce risk. For example, the team found that the EM-1 upper stage—the non-human rated Interim Cryogenic Propulsion Stage—was more tolerant of MMOD than previously assessed. Further, two key safety-related items were identified. First, execution of the ascent abort test sooner than currently planned would provide early insight into that critical safety system. The test could more quickly inform the design about needed improvements, thus increasing safety as well as saving time and money. As a consequence, the Orion program decided to put the necessary FY 2017 decisions and funding in place to support this acceleration.

The second item focused on the schedule gap of some 33 months between the EM-1 and EM-2 launches, due in part to the time required to modify the Mobile Launch Platform (MLP) for the Exploration Upper Stage (EUS). EM-2 and all follow-on crewed missions are designed to use the EUS, as it is a fully human rated upper stage. However, it raises the stack height some 30 plus feet. If the existing MLP is modified rather than building a new MLP specifically designed for EUS, an operational launch gap is created, because no launches can take place while the MLP is under modification. This creates potential safety risks as the skills and number of the ground and launch workforce may naturally attrit over such a long inactive period, resulting in a critical loss of experience and knowledge. While other critical path items from EM-1 to EM-2 must be watched, building a second MLP mitigates that risk as construction can begin independent of the EM-1 mission. Having a second MLP allows focus to remain on other safety items and reduces distraction from a time-critical hardware build. In addition to operational risk mitigation, the Nation would have operational flexibility with two differently configured MLPs. The ASAP strongly recommends that NASA be resourced and begin construction of a second MLP as soon as possible.

C. Test and Verification Schedule

From initiation, all three Exploration program elements—Orion, SLS, and Ground Systems Development and Operations—have been on a very tight schedule. In last year's ASAP report, we documented our concern that schedule pressure could cause an erosion of the ground and flight testing content that had been planned to prove out the various subsystems and their integration prior to the first flight. We officially recommended that the Agency consider schedule relief as an alternative to reduced test content. Although the Panel will continue to monitor the situation, NASA has taken our recommendation seriously and is maintaining test content. The Panel strongly encourages the Program to continue to keep safety its priority and maintain its stated intent of "We will not fly until we are ready."

When considering schedule, it is well to remember that some of the test articles, when assembled, are many stories high and have required the construction of enormous rigs to carry out the required testing. Structural test article (STA) testing, one of the most complex types of testing, is currently taking place at multiple locations. For example, the Integrated Spacecraft and Payload Element structural testing was completed in April 2017, and testing of the Engine Section STA was begun in September 2017. The huge liquid hydrogen (LH2) and liquid oxygen (LOX) tank test stands are complete, and the STAs will ship to test in mid-2018 in order for testing to begin around the end of the year. The need to move such large objects to their testing location and then install them into equally large and complex test facilities represents a technical and safety challenge of its own, even in the problem of transportation and handling. Such challenges always put the program schedule at risk, increasing the pressure to reduce content to save schedule.

FIGURE 4. LH2 Tank Test Stand

FIGURE 5. LOX Tank Test Stand

In summary, testing continues and has been very successful so far. The current EM-1 launch date is the end of 2019, but further slips are possible, even though the Program continues to have successful technical accomplishments.

D. Orion Heat Shield

In the ASAP's 2016 report, we noted that the original Avcoat monolithic honeycomb design exhibited cracks in the gore seams and reduced acreage material strength in early testing. As a result, NASA decided to switch to a molded block Avcoat design. This new design has now been under development for the last two years. Given the significant design switch, the ASAP raised a concern as to how NASA would be able to detect a critical flaw in the bond between the molded block tiles and the substructure. In 2017, we continued to track the development of both the block form factor heat shield and the advancement in non-destructive examination (NDE) techniques needed for flaw detection. Recent observations this year conclude that newly developed NDE now allows a thorough bond inspection, and block component testing has shown a significant increase in heat shield strength. While EM-1 remains the first full flight test of the complete shield and may reveal unknown challenges, these developments are positive and currently indicate a lower risk than previously assessed.

FIGURE 6. Avcoat Block Heat Shield Installation Underway

E. European Service Module

The ASAP has previously reported that some systems in the European Service Module (ESM) were zero fault tolerant, hence representing potential single point failures. In general, these problems arose due to the plumbing and valving configuration associated with the fuel system feeding the propulsion and reaction control system (RCS). In addition, some of the individual components were zero fault tolerant due to their seals and bellows configurations. NASA currently lists some 14 specific system issues relating to the ESM propulsion and RCS systems.

We have previously reported that these existing system designs could represent additional safety risk to the crew. However, for the 14 specific system issues documented, NASA has worked with the European Space Agency and has committed to either incorporating design changes or conducting detailed risk reviews leading to formal risk acceptance by appropriate leadership levels. To reduce risk as quickly as possible, NASA has agreed to incorporate some of the identified actions prior to EM-2. To date, four systems have been redesigned, two detailed risk analysis and subsequent acceptance of low risk have been carried out, and two additional changes are now in final review. Thus, 8 of the 14 issues will be addressed before EM-2. In addition, NASA has committed to additional risk reduction for EM-3 and EM-4 with the incorporation of the mitigation action on the remaining issues.

F. Micrometeoroid and Orbital Debris Risk

MMOD remains a top program risk for EM-1 and EM-2. In part, the risk is being mitigated through a tradeoff between remaining in LEO, where systems and equipment can be more easily checked and the crew could be quickly returned to Earth in an emergency; or making an early transition to high Earth orbit—or even a lunar transit orbit—where the MMOD risk is lower. From a crew safety perspective, the LEO checkout period is especially important for EM-2, as it will be the first flight of the ECLSS. As reported last year, the ASAP believes that the Program team has done a reasonable job of designing mission profiles as optimally as possible, balancing both concerns against crew and vehicle safety. In the future, although MMOD will remain a high-risk item, operations will continue to reduce LEO time as the system matures and experience is gained. Eventually, since the system is to be used primarily for deep space exploration, it will pass quickly out of LEO and reduce the exposure to MMOD danger.

G. Significant Incidents and Close Calls in Human Spaceflight: A Study in Their Applicability to Exploration Systems Development

The ASAP compliments the Safety and Mission Assurance (S&MA) TA and members of the ESD safety team for their initiative in conducting a comprehensive study of past significant incidents and close calls that have occurred in human space flight. The basis for the study was the document, "Significant Incidents and Close Calls in Human Spaceflight" published by JSC. Principal authors are Dr. Nigel Packham, JSC S&MA Flight Safety Officer (FSO) and Mr. Bill Stockton, Science Applications International Corporation lead, FSO Support Team.[1] This document chronicles some 186 safety incidents going back to the 1960s and includes operations by SR-71, X-15, Soyuz, Shuttle, and ISS (See Appendix A to this Report).

The ESD S&MA team examined all documented incidents and in a two-phase study determined their applicability to EM-1 or EM-2. That applicability was categorized as either "directly" (Phase 1-same system, environmental, human error) or "generically" (Phase 2-similar system). The results showed 67 events were applicable from Phase 1 and 90 from Phase 2. The team then prepared recommendations for the Program to mitigate the risk for each event.

---

1 See *https://spaceflight.nasa.gov/outreach/SignificantIncidents/index.html* for interactive graphic.

III. Commercial Crew Program

A. Certification for Crew Flights to the International Space Station

The CCP continues to make steady progress toward providing the capability for crew transportation to LEO and ISS. Both providers are planning for test flights in 2018, with the first Post Certification Missions to ISS no earlier than November 2018. NASA has procured seats onboard Soyuz 58 and 59 for transportation of U.S. Astronauts to ISS through late 2019. The following table summarizes the current planning dates for U.S. crew access to ISS.

Event	Planned (as of Nov. 2017)
SpaceX Demo 1 (No Crew)	March 2018
SpaceX Demo 2 (Crew)	August 2018
Boeing Orbital Flight Test (No Crew)	August 2018
Boeing Crewed Test Flight	November 2018
SpaceX PCM 1	November 2018
Soyuz 58 Launch	March 2019
Soyuz 59 Launch	May 2019
Boeing PCM 1	May 2019
Soyuz 58 Land	September 2019
Soyuz 59 Land	November 2019

While the Panel is unaware of any efforts to purchase additional Soyuz seats after Soyuz 59, the current planning dates would allow NASA to utilize the commercial providers to maintain uninterrupted access to ISS. However, based on the quantity, significance, and associated uncertainty of work remaining for both commercial providers, the Panel believes there is a very real possibility of future schedule slips that could easily consume all remaining margin. There are several major qualification and flight test events that historically are schedule drivers or could reveal the need for additional work. These include pyro shock qualification tests, parachute tests, engine hot fires and qualification runs, abort tests, and both uncrewed and crewed

FIGURE 7. SpaceX's Merlin 1D Full Thrust Testing

flight tests. Also, SpaceX is still working the redesign and qualification of the Composite Overwrap Pressure Vessel (COPV) helium tanks for the Falcon 9 (F9), in response to the F9-29 mishap. This issue, which has significant work ahead, is covered in more detail in a subsequent section.

In addition to the technically complex test and qualification work remaining for the providers, NASA also has a significant volume of work remaining. The final phase of the NASA Safety Review process, where verification evidence of hazard controls is submitted by the provider and dispositioned by NASA, remains ahead. This is in addition to the majority of CCP 1130 and ISS 50808 requirements verifications, where the provider submits the verification evidence via Verification Closure Notices (VCNs) for NASA review and disposition. Even though it is common for verification packages to be completed late in the certification process, the sheer volume of work that remains to adequately review and disposition the VCNs is significant. If NASA were to determine that the evidence submitted does not meet the verification standard on some requirements or hazard controls, additional time would likely be required to resolve the issue with the provider.

FIGURE 8. Boeing Structural Test Article

Despite the volume of remaining work, technical challenges, and end of the Soyuz transportation for U.S. crews, the ASAP sees no evidence that the CCP leadership is making decisions that prioritize schedule over crew safety. However, we expect to see several significant certification issues brought to culmination in the next year that will require NASA risk acceptance decisions at a very high level within the Agency. It is possible that in some cases, the most favorable schedule options will require a decision to accept higher risk. The Panel advises NASA to maintain awareness of potential schedule pressure. We note that the strategy of funding two providers was adopted, in part, to avoid a situation where NASA would be forced to accept undesired risk to maintain crews on ISS. Maintaining U.S. presence on ISS, without acquiring additional Soyuz seats, requires one provider be certified and ready to fly crew to ISS by mid to late 2019. Certification of the second provider could happen after that time.

It is worth noting that certification represents the foundation upon which the safety, reliability, and performance of the system rests. It encompasses a validation that all requirements have been properly covered and adjudicated between the provider and NASA. It means that the system configuration

is known and fixed. The hardware and software in question must have complied with the adjudicated requirements, and its performance must have been verified in accordance with agreed-to testing, analysis, and/or other certification artifacts as delivered and approved. Each vehicle flown under the certification must have the hardware properly accepted (without violating the qualification limits) and the configuration verified to comply with the certified configuration. Successful achievement and compliance with certification requires that the provider have disciplined engineering and operations processes along with adequate controls to prevent process escapes. Traditionally, this is considered part of systems engineering, but disciplined processes can also be applied by providers employing non-traditional approaches. In February, the ASAP made the following formal recommendation to NASA:

> The Panel recommends that NASA require the Commercial Crew providers to produce verifiable evidence of the practice of rigorous, disciplined, and sustained system engineering and integration (SE&I) principles in support of the NASA certification and operation of commercial crew transportation services to the ISS.

In response to the recommendation, NASA assessed its insight into and oversight of both providers' engineering practices. NASA reported the following action plan to the Panel:

- Review latest SE&I-related plans and processes
- Increase audits of compliance to SE&I-related plans and processes
- Conduct system-level design reviews to ensure interfaces and inter-relationships of subsystems have been adequately addressed

While the Panel commends NASA for these actions and its acknowledgement of the need for increased surveillance of at least one provider, NASA should expect both providers to exhibit a safety ***culture*** appropriate for human space flight. This requires each provider to internalize the ***value*** of highly disciplined processes and controls and engrain them into the company culture. We intend to hold this recommendation open until we see evidence of achieving this outcome. The investigation into the recent mishap during Merlin engine qualification and execution of critical qualification and validation tests will provide an opportunity to gauge the progress of this effort at SpaceX.

B. Probabilistic Risk Assessment for Loss-of-Crew

The CCP Probabilistic Risk Assessment (PRA) requirement for LOC covering a 210-day mission to ISS is 1 in 270. In clarifying the requirement, the CCP allocated 1 in 200 to the providers' systems, with the remainder allocated to operational mitigations such as on-orbit inspection. There is also a specific PRA requirement for the ascent and entry phases–1 in 500 (combined). The Panel has been monitoring the providers' progress in working toward the LOC requirements, and it appears that neither provider will achieve 1 in 500 for ascent/entry and will be challenged to meet the overall mission requirement of 1 in 200 (without operational mitigations).

<table>
<tr><th colspan="3">Loss of Crew (LOC) Probabilistic Risk Assessment (PRA) Requirements</th></tr>
<tr><td colspan="3">ISS Mission (1 in 270)</td></tr>
<tr><td colspan="2">Commercial Crew Transportation Systems (1 in 200)</td><td rowspan="2">Operational Mitigations</td></tr>
<tr><td>Ascent & Entry Mission Phase (1 in 500)</td><td>Orbital/Docked Phase</td></tr>
</table>

PRA is a well-recognized tool that allows the assessment of hazards and their relative contribution to risk to assist in the design and development process. History has shown that the PRA values should not be viewed as an absolute measure of the actual risk during operations. When developing new human space flight vehicles, the unique nature of these systems and limited test data results in large uncertainties in the PRA numbers. In our opinion, the most valuable element of the PRA analysis is the identification of the major risk drivers, which can then be mitigated by design changes, additional testing, or other controls. While there are large uncertainties around the specific numbers resulting from the analysis, the primary risk drivers identified are the same for both commercial systems:

- MMOD damage during docked phase (affects overall mission requirement)
- Parachute performance (affects overall mission and ascent/entry requirements)

Based on the PRA identification of these risk drivers, NASA and the providers have applied resources to improve the capability to withstand MMOD impacts, better understand the ability to tolerate MMOD damage, and perform additional parachute tests. Operational mitigations such as on-orbit inspection and abort weather Launch Commit Criteria were also directly informed by the PRA results. Ultimately, the NASA PRA requirements were established to set an analytical risk standard for the Commercial Crew systems that was significantly better than the Space Shuttle and challenge the providers to make their systems safer by focusing resources on critical areas of the design and operations. The Panel commends the NASA team and providers for using the PRA tool to effectively improve the risk posture. However, the likelihood remains that the providers will not meet all the PRA requirements, and NASA will need to determine if the risk portrayed by the analysis, with its large uncertainties, is acceptable. We encourage NASA to fully consider all factors, including the rationale and environments used to derive the original requirements, when evaluating the final PRA LOC numbers for both providers and making any risk acceptance decision.

C. Falcon 9 Helium Tank Redesign and Qualification

At the publication of last year's ASAP report, the investigation for the F9-29 mishap was ongoing. SpaceX conducted the investigation with NASA, the U.S. Air Force, and FAA participation. NASA also conducted its own independent analysis of the evidence. Early in 2017, an ASAP member attended SpaceX's briefing to NASA, covering the investigation results and conclusions. The Panel also received a copy of the mishap report and was briefed separately by SpaceX. The SpaceX investigation did not find a single most probable cause of the initiating event, instead identifying several credible causes involving the COPV helium tanks. All credible causes were similar in that they involved LOX trapped between the overwrap and the liner with subsequent ignition through friction or other mechanisms. The evidence recovered from the mishap showed indications of buckles in the COPV liner where LOX was likely trapped. Acting from the report findings, SpaceX was able to recreate a buckle event during a COPV test. Additional testing allowed SpaceX to identify specific conditions which would cause a buckle and trap oxygen in the gap between the liner and overwrap. Using this data, SpaceX modified its helium loading configuration, process, and controls to ensure that the COPVs would not be exposed to these identified conditions and, accepting any residual risk, successfully resumed commercial launches with the existing COPV design. However, to further improve safety, SpaceX and NASA agreed that a redesign of the COPV was necessary to reduce the risk for missions with crew onboard.

Using what they learned from the mishap investigation, SpaceX redesigned the COPV and NASA started a rigorous test program to characterize the behavior of the new COPV in the cryogenic oxygen environment. The Panel considers this to be the most critical step in clearing the COPV for human space flight, as it allows NASA and SpaceX to *identify the credible failure mechanisms, hazard scenarios and controls, as well as understand the safety margins on the system*. With this information, SpaceX can develop a proper qualification program and NASA can decide on the acceptability of the hazard controls and residual risk. The Panel strongly supports this effort and notes that this is another example of the commercial providers and NASA working together to solve a very difficult technical issue. *In our opinion, adequate understanding of the COPV behavior in cryogenic oxygen is an absolutely essential precursor to potential certification for human space flight.* It also should be noted that NASA and SpaceX are working on an alternative helium tank design should the COPV certification efforts fail. However, the heavier weight of the alternative design could require significant modifications to the supporting structure to handle the additional loads. Additionally, if the alternative tanks are only flown for NASA missions, the potential hazards and impacts arising from operating a unique F9 vehicle at a relatively low flight rate (as compared to SpaceX launches for other customers) would need to be carefully assessed.

The discussion of COPVs would not be complete without a mention of SpaceX's plan to load densified propellants after the crew is onboard the Dragon2 (often referred to as "load and go"). In last year's report, the Panel urged NASA and SpaceX to focus on "…understanding how the system functions in the dynamic thermal environment associated with 'load and go' so that… previously unidentified hazards can be discovered." While the COPV efforts are consistent with that advice, we advise NASA not to discount the other potential hazards associated with loading cryogenic propellants—particularly LOX. Fully assessing all the hazards is critical in determining the best time to load the crew onboard the Dragon2 for launch after considering the risks and benefits associated with such a decision.

IV. International Space Station

A. Overview

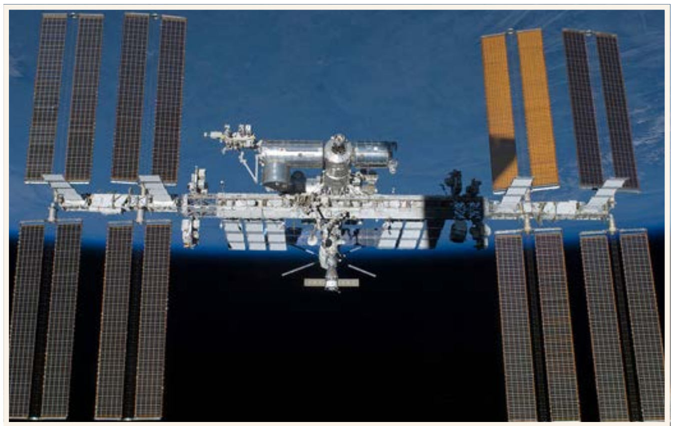


FIGURE 9. ISS on Orbit

The ISS remains the centerpiece of NASA's currently operating human space flight program. It is presently the only human-occupied space vehicle that NASA, or its supporting contractors, have in operation. Despite this fact, some in the general public may not be aware that it has been continuously occupied and operated by U.S. crews since Expedition 1 arrived in 2000. During that time, it has circled the Earth almost 100,000 times, traveling over 2 billion miles without a significant injury. This is an impressive record, especially considering the challenges of operating such a complex vehicle 24 hours a day, 7 days a week, in LEO's hostile vacuum, thermal, and radiation environment. This record is a testament to the ISS Program's continuing excellent management. These challenges continue to grow as the ISS components gradually progress towards their life limits, and the threat of MMOD impact grows every year.

B. Test Bed for Exploration

In addition to the well-publicized, scientific research that is carried out on the ISS daily, an additional major benefit is serving as a "Proving Ground" to develop and test the technologies that will be required for humans to travel into deep space, including to Mars. The capabilities that must be developed or better understood include both the hardware that must operate for long periods of time without support from the Earth and the psychological and physiological responses and capabilities of the humans who will one day conduct exploration. One example of the type of technologies currently being explored on the ISS that could lead to more efficient and safer habitat on the journey to Mars is the Bigelow Expandable Activity Module (BEAM), currently operating successfully attached to the ISS. Others include highly reliable environmental control technologies that will be required to provide a

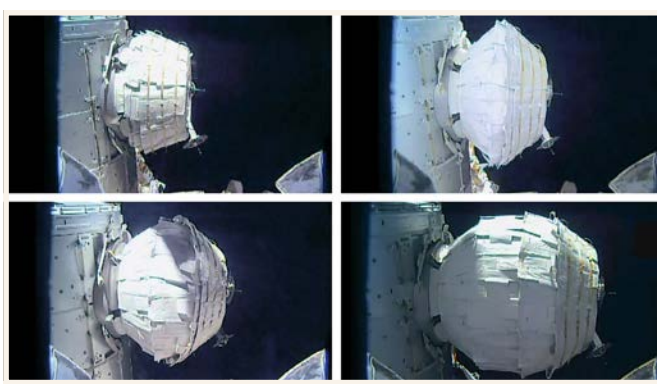


FIGURE 10. BEAM Deployment

safe environment for astronauts on their long journey to the Red Planet and research into the long-term effects of microgravity.

C. Aging Hardware

ISS begins its 18th year of hosting crews on-orbit during 2018, and is slated to continue service into 2024 with the potential to serve as long as 2028. Day-to-day operations on Station are not without occasional challenges related to unanticipated equipment failures. While there have been no incidents to date which have risen to the level of a recordable mishap, many of the emergent failures have been successfully mitigated due in large part to the rigorous training and adaptability of the ISS crew, as well as the sound engineering, spares planning, and technical guidance from ground control personnel. A recent extravehicular activity (EVA) to repair a leaking External Active Thermal Control System Loop serves as one example of the type of maintenance requirement aboard ISS that will clearly require an effective Extravehicular Mobility Unit (EMU) maintenance program. During this EVA, astronauts were able to stop a persistent ammonia leak by isolating and venting a Radiator Beam Valve Module. This leak had been closely monitored by the ISS Program since its initial discovery in 2013, and was resolved after a thorough technical analysis of both risk and feasibility. As Station continues to mature toward its eventual retirement, we can foresee a potential for more frequent equipment anomalies and associated EVAs to support repairs. The ASAP will continue to closely monitor the ISS program for any indications of negative trends in this regard.

The Panel believes that EMU readiness and availability will become increasingly important to ISS sustainment through scheduled retirement. This year, we will closely monitor EMU readiness, particularly on-orbit EMUs and their critical subsystems, including Orbital Replacement Units (on-orbit interchangeable components). A number of documented anomalies have been observed since the EMUs entered service and, although there has not been a specific negative trend identified to date, these have impacted on-orbit maintenance capability. NASA's Human Exploration and Operations Mission Directorate should closely examine EMU sustainment plans and practices to ensure that ISS can maintain continuous operations until the ISS retirement plan is executed. Once the third Commercial Cargo provider demonstrates initial capability, there should be increased opportunity for EMU rotations, which will allow for maintenance to be conducted in ideal cleanroom conditions at JSC as needed. Additionally, the Agency's plan to develop a replacement EMU for future exploration missions beyond LEO should consider the ISS retirement timeline. As ISS approaches the end of its service life, it is critical to the success of the follow-on EMU program to capitalize on the ISS availability as a flight testbed.

D. Commercial Resupply

ISS's continued safe operation has been made possible in large part by the ongoing Commercial Resupply Services (CRS) flights that have been in operation for the last five years. Both Orbital/ATK and SpaceX have successfully delivered essential consumables as well as other logistical support to ISS

FIGURE 11. Cygnus Approaches Canadarm2

FIGURE 12. Dragon Berthed to ISS

FIGURE 13. Dream Chaser on Armstrong Runway at Dawn

during this period. Without this support, the ISS would have to be de-crewed, which would present both immediate and longer-term safety concerns: the inability to perform essential ISS maintenance tasks on orbit, and the absence of efforts to reduce risk in future operations due to lost learning opportunities. In addition, SpaceX has the capability to return cargo to Earth to support both required maintenance on ISS equipment, such as EMUs. Two CRS providers have supplied the ISS program with redundant capability to deal with mishaps by one of the providers that would have otherwise threatened ISS resupply continuity and possibly ISS continuous operation. In the early 2020s, robust commercial resupply will be further enhanced when Sierra Nevada begins cargo resupply missions to ISS. Not only will this expand supply robustness, but Sierra Nevada's Dream Chaser will also be able to bring back cargo and equipment. This will be particularly valuable for various equipment maintenance tasks.

E. Deorbit Planning

When ISS construction began in 1998, NASA and its International Partners planned to eventually develop a controlled reentry capability before the scheduled termination of the Program. Until such a capability could be developed, they recognized that a catastrophic emergency could potentially result in a subsequent uncontrolled vehicle reentry,[2] and the potential debris impact zone would be at a random spot on Earth somewhere within the Station's 51.6-degree orbit inclination limits as shown by the magenta-colored latitudes indicated in Figure 14. While many of the ISS components are low-density and would simply tear off and burn up in the atmosphere upon reentry, many are much higher density and would be expected to reach the Earth at a relatively high energy, potentially resulting in damage or injury on the ground if impact were in a populated area. A common practice at the time ISS was begun was to rely on the low probability of orbital debris impacting a populated area to protect those on Earth from its effects. Since that time, international norms and treaties have made this approach unacceptable, and efforts have been underway for several years to provide for the controlled reentry of the ISS to a safe impact location when it is deorbited. Everyone hopes that the need for this process will be many years from now at the end of the ISS useful life. But the potential for a catastrophic failure and need to evacuate the crew—such as significant MMOD impact or an uncontrolled fire or hull breach—must be recognized and dealt with now to prevent an uncontrolled reentry. NASA estimates that the probability of a need to evacuate the Station is approximately 1/60 per year,[3] or an approximate 12 percent chance during the seven remaining years of the currently projected Station life. That probability increases proportionally if Station life is extended.

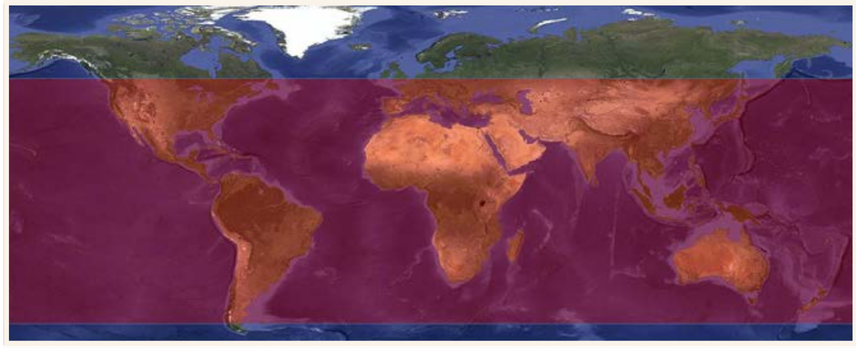


FIGURE 14. Area within which surviving ISS debris has potential to impact

NASA has been working for several years to develop the planning, software, and hardware changes that are necessary to provide a controlled deorbit capability as soon as possible. Last year, the ASAP commended NASA's commitment that established a new ISS Deorbit Strategy Program Manager position to oversee these efforts. This year, NASA has taken several actions to prepare, as best it can, for the potential for an emergency deorbit situation. The Program has developed a notional timeline for the various actions that need to be accomplished to prepare for this eventuality. An "ISS Deorbit Strategy and Contingency Action Plan" has been drafted and is nearing approval. The most recent action is to develop and soon send to orbit and install "gas trap plugs" that will prevent leakage of propellants needed for deorbit if there is a hull breach.

The actions accomplished to date will give some limited control of the reentry zone but do not yet provide for the accurate, reentry-point control needed to limit the debris field to a desired location. While several required actions are still ongoing at NASA, much of the significant remaining actions

---

2 "Final Tier 2 Environmental Impact Statement for International Space Station" May 1996, *https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19960053133.pdf*

3 Draft ISS Deorbit Strategy and Contingency Action Plan, SSP 51066

to prepare the emergency deorbit capability now rest with the ISS Russian partner. Until these planning actions are completed, the capability to accurately deorbit the ISS to a specific safe location in the event of an emergency does not yet exist. We strongly encourage these precautionary measures to be completed in a timely manner. Firm planning and capability should be in place in the unlikely event that emergency deorbit might be required at any given moment without notice. These actions should include the hardware and software requirements for deorbit, as well as the international decision process for Station abandonment that would be necessary at the highest levels within a short time period.

V. Deep Space Exploration

The 2017 Transition Authorization Act reinforced the direction that NASA had been given by the previous Administration to focus on sending humans to Mars. During the past year, NASA has continued to identify capabilities, technologies, and risk reduction approaches towards that objective. In last year's report, the Panel acknowledged the positive progress that NASA had achieved in this endeavor. However, we noted that a more focused evaluation of potential mission architectures was required to gain confidence in the overall plan viability and sustainability, as well as the appropriate risk posture. We were encouraged to see substantial progress made in 2017 in the framework for exploration beyond LEO that advances the level of detail for the journey to Mars. This framework has been titled "Deep Space Gateway" (DSG).

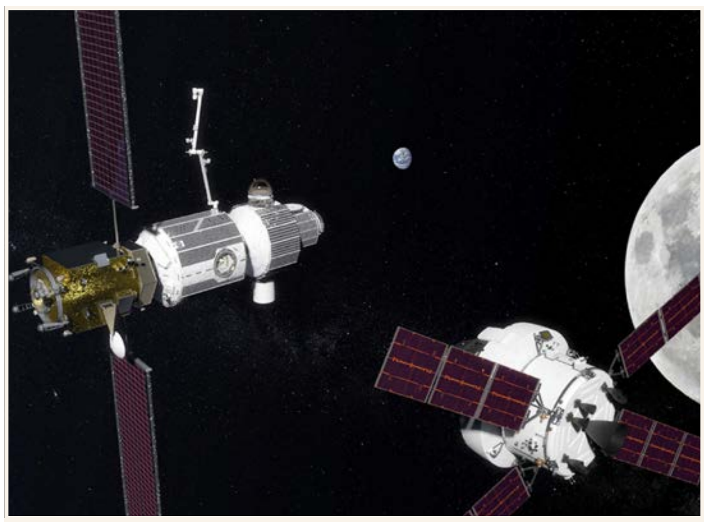


FIGURE 15. Deep Space Gateway Concept

The DSG framework defines an exploration approach that appears to be flexible and include both industry and international collaboration, while addressing the risk management and mitigation activities necessary for journeying on to Mars. The DSG, stationed in cislunar space, takes advantage of the near-Earth lunar neighborhood to push the boundaries of human engagement further from LEO, while still remaining within a few days of home in the event of an emergency. The framework design flexibility provides NASA and its collaborators the potential of experimenting and testing multiple technologies and operational paradigms. It is an appropriate next step in the long series of activities that will lead humans to the Red Planet.

Concurrent with NASA's definition of the DSG project, the new Administration has been coalescing around its approach for space policy. The newly reinstated National Space Council met for the first time on October 5, 2017. At that first meeting, a new vision for human exploration was announced:

> *"The United States shall lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations."*

The DSG framework has the flexibility to accommodate this policy direction. However, the larger question is related to available resources. The addition of new hardware development programs will challenge an already constrained resource environment. For example, if NASA were directed to develop a lunar lander in addition to maintaining schedule and content on its existing programs, it would need additional resources to do so, regardless of whether or how NASA might choose to implement international or industrial partnerships. In addition, the implementation choice could potentially affect the risk posture and safety of some existing programs.

Consequently, the ASAP has two major areas of concern that will be receiving attention as the dynamics of the policy change and the development of the DSG moves forward:

- As the DSG concept is matured and implemented and the roles for NASA, industry, and international partners are identified, we are looking forward to understanding the integrated scope and priorities for the testing and risk reduction activities that will be undertaken in cislunar space, and potentially, on the lunar surface.

- If the direction for NASA in cislunar space now includes a mandated return to the Moon's surface and no additional funds are supplied, it will create inevitable pressures on existing programs to execute safely.

Regarding the first concern, the Panel is interested in the testing or methodologies targeted for mitigating risks related to expanding human presence to Mars. Clearly articulating the connections between the requirements for a Mars mission to milestones for the DSG—and other forms of "proving grounds"—will also give NASA an understanding of the priorities and criticality of activities, allowing the Agency to make better decisions on collaboration potential. Included in the discussion on risk mitigation should be the role of any lunar surface activities.

Regarding the second concern, budget and resource allocation remains a challenging area for the Agency. NASA has more projects in development than at any time in the last several decades. All are critical for the future trajectory of human space flight in the U.S., and all are hitting important milestones in the next two years. The additional requirement to develop a lunar lander to support surface activities, without the commensurate funds, potentially threatens the sustainability of existing programs. The DSG concept facilitates NASA's ability to work in collaboration with industry and international partners, and that flexibility should be exercised. If NASA would have to provide a portion of the development funds for a vehicle designed for sending and returning humans from the lunar surface, the funding source needs to be identified such that existing programs are not compromised. However, by collaborating on lunar surface exploration—with industry or one of the international partners providing the necessary transportation system—the budget impact may be minimal. Nevertheless, if NASA expects to use the results of the surface studies to enhance its Mars mission, it will still need to ensure any risk reduction activities planned will be timely.

Initial concepts for the DSG include a proposed new concept on human rating space systems as well as achieving redundancy. The DSG is a collection of multiple modules and includes the Orion crew capsule when crew is present. (The Orion transports the crew between LEO and the DSG.) The Orion capsule will be fully human rated, with appropriate redundancies in design and operation to mitigate loss of crew and minimize loss of mission. NASA is proposing a system-level design concept for the DSG that incorporates stringent human rating when the Orion is present, but proposes some relief when Orion is absent. Human rating of the DSG will be achieved, fundamentally, by the combined capabilities of the modules and the presence of the Orion vehicle; all components of the system are important, no single piece is enough. The operational concept being proposed is that if a critical system that irreparably impacts crew survivability fails, the crew response will be to egress the DSG, ingress Orion, and depart. The system-level concept being proposed thus increases risk for loss of mission while maintaining the stringent human rating standards to protect against loss of crew. The Panel acknowledges the new approach and looks forward to hearing more details about its implementation.

NASA has also reported that it will be considering alternative design approaches for achieving redundancy in the DSG. Taking advantage of experience gained on the ISS, NASA will pursue design concepts targeted at implementing dissimilar redundancy as a more robust approach. For example, there are redundant carbon dioxide removal systems on the ISS, but they are completely different systems in design and technology and totally independent of each other. Regardless of the ultimate design approach, NASA stated that the main goal remains the same—ensuring adherence to either loss of crew or loss of mission safety requirements.

In general, the Panel feels the DSG framework has excellent potential for appropriate risk mitigation related to a journey to Mars and looks forward to the ongoing detailed concept development.

VI. Aviation

A. Introduction

During 2017, the Panel's schedule afforded fewer opportunities to assess Aeronautics and Air Operations than were available during 2016. However, we did have the opportunity to receive an update on the status of the NASA Aircraft Management Information System (NAMIS) as well as a robust discussion on NASA aircraft capabilities improvements related to compliance with the NextGen Air Traffic Control initiative. Additionally,

FIGURE 16. NASA Airborne Science Program's P-3 Orion research aircraft departs for another science mission.

the Panel was represented at the IAOP and Aircraft Advisory Committee meetings in December 2017, which covered topics as diverse as Unmanned Aircraft Systems (UAS) regulatory development and operations to Public Aircraft Operations and Contract Air Services.

B. NASA Aircraft Management Information System

During 2017, the Panel addressed the ongoing NAMIS issue. In the previous two annual reports, NAMIS emerged as a topic area of serious concern, primarily due to program misalignment and persistent budgetary shortfalls that threatened its viability as a reliable aircrew readiness and aircraft configuration management tool. We are pleased to find that funding for NAMIS was realigned under the Office of Chief Information Officer (OCIO) as a “funded Information System Application” during FY 2017. This administrative realignment is an important step, because it should help alleviate some of the budget instability that had limited maintainability and required updates of NAMIS software in previous years. It should be noted that even though the NAMIS operating budget has been somewhat stabilized under the OCIO funding, some budgetary instability remains in the form request versus grant shortfalls. For example, for FY 2017, the approved grant was $4.2 million, but at some point during the FY, that was reduced to $3.9 million. With a relatively small operating budget, even small reductions such as this can result in reduced capacity to make critical, safety-of-flight software changes.

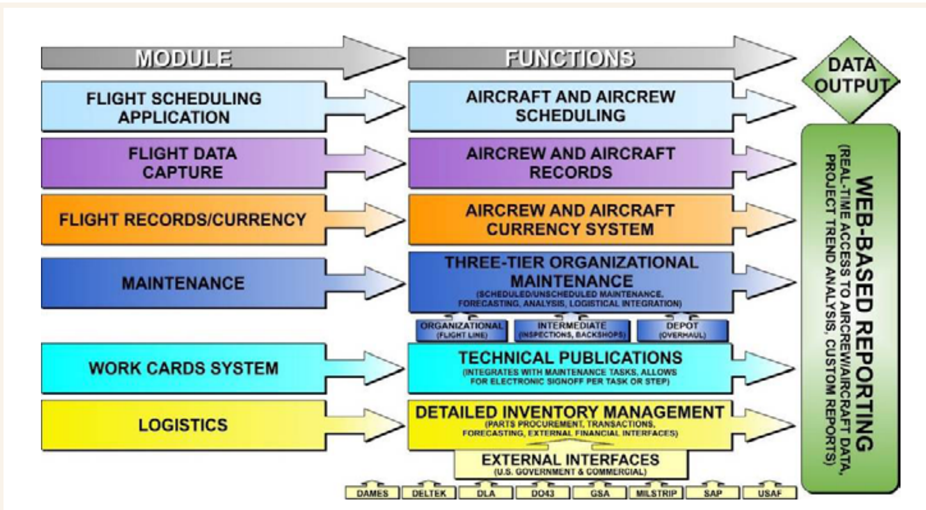


FIGURE 17. Different NAMIS software modules and their functions, as well as interfaces with external systems.

Another commendable improvement in NAMIS program management is the maturation of the Configuration Control Board (CCB) process and its efforts to evaluate risk as it prioritizes software change requests. The CCB’s efforts have resulted in a marked decrease in overall number of open

NAMIS software change requests and, more importantly, the process identifies and elevates the priority of critical safety-of-flight-related changes.

From an aircrew readiness perspective, NAMIS remains the sole means to monitor individual aircrew qualifications and flight currency. On the surface, having a software system with this capability and level of fidelity sounds like a fairly simple task, but it is, in fact, quite difficult to track properly. What makes this such a challenge is the fact that each NASA Center that has operating aircraft has a unique stable of airframes with various type/model/series represented, combined with NASA pilots who are generally qualified in multiple combinations of these aircraft. For example, a pilot assigned to JSC who is qualified in a single aircraft is required to fly a minimum number of hours and conduct a minimum number of landings/approaches per month/year in that aircraft. Compare that simple tracking formula to one that must track a pilot who is qualified in the T-38, WB-57, and the Gulfstream simultaneously. To maintain currency in all three of these aircraft, the pilot must fly each airframe with enough frequency to be proficient, but not as frequently as if they were qualified in each one separately. In other words, the tracking formula, and the program code in NAMIS, is different and may require a software change request to work correctly. The Panel will continue to monitor the status of NAMIS throughout 2018, paying close attention to funding consistency, change request backlog, as well as Agency discussions/decisions regarding future inclusion of UAS under the NAMIS umbrella.

C. Aircraft Operations and Fleet Updates

In December 2017, Panel representatives attended the IAOP held at NASA Headquarters. This engagement opportunity provided us with detailed insight into almost every facet of NASA aircraft operations.

NASA operates a diverse portfolio of aircraft to support a wide variety of missions, ranging from astronaut training to worldwide Earth science missions. Many are unique, one-of-a-kind aircraft that are highly modified to meet mission requirements. As these airframes age, a long-term plan is required to ensure NASA maintains the capability to conduct these critical Earth science missions. For example, NASA's DC-8 was built in 1969, and has been flying with NASA since 1985. Replacing this airframe requires a long-lead-time plan that will likely include a significant period of rework and modification prior to initial operational capability. The Panel commends the efforts of the Aeronautics Research Mission Directorate (ARMD) and their forward-looking vision to ensure seamless Earth science flight research capability.

FIGURE 18. Armstrong Flight Research Center's highly-modified DC-8 Airborne Science Laboratory

Additionally, NASA's aircraft fleet must maintain the most current communications and navigation technology to operate unimpeded in the National Airspace System as well as in airspace systems around the globe. The ARMD has done an exceptional job managing these avionics system upgrades across the NASA aircraft portfolio to meet requirements to operate safely in special airspace such as Reduced Vertical Separation Minimums airspace, North Atlantic Organized Track System routes, and to meet forthcoming year 2020 Automatic Dependent Surveillance-Broadcast "out" to meet FAA NextGen Air Traffic Control requirements. These avionics capability upgrades all come at a cost, and priority should be given to continue funding these critical safety-of-flight upgrades.

D. New Aviation Horizon

FIGURE 19. NASA Commercial Supersonic Technology Demonstrator

Last year, the ASAP report discussed the proposed NASA Program entitled "New Horizons in Aeronautics." The Program was envisioned to highlight NASA's increased emphasis in aeronautics, air traffic management, aircraft environmental impact, and advanced aircraft technology, often referred to as "X-Planes." The Panel praised this effort by the Agency to work towards sustaining U.S. leadership in flight science and aircraft design. At that time, due to the timing of budget actions, we were uncertain if this important initiative would obtain the necessary startup funding. We are pleased to report that funding was provided, and the work was initiated in 2017. More importantly, sustaining funding has been requested in the 2018 and out-year budgets.

The ASAP's only caution expressed at that time was that any endeavor involving aircraft and advanced technology involves risk both to those on the ground and to the crew who pilot the test aircraft. Many of the technologies which will be investigated—for example, hypersonic and commercial supersonic flight, aircraft icing, and advanced propulsion—involve considerable risks, many of which are still unknown.

Therefore, we continue to emphasize our caution and urge NASA to move into the unknown while applying its full effort to risk identification and mitigation. Exploring the unknown can never be without risk, but taking unnecessary risk should not be tolerated. This important Program will be one which we will monitor closely, especially as NASA moves into X-Plane flight operations.

VII. Enterprise Protection

Throughout 2017, the ASAP monitored NASA's progress on its Enterprise Protection (EP) Program and related risk management activities. NASA has also received recent pressure from both the Administration—through a May 2017 Presidential Executive Order—and the NASA Office of Inspector General (OIG)—through numerous audits—to broadly account for the current NASA risk posture across the security enterprise. To NASA's credit, Agency leadership has shown demonstrated awareness of the risks, and a few small steps have been taken toward an improved risk posture for the physical, corporate, and mission layers of the enterprise. However, much of NASA's efforts this year have been focused on identifying areas of risk, while the implementation of risk reduction generally remains a topic for future work. From the ASAP's perspective, the implementation of broader risk reduction measures, and how such measures are implemented through governance, will be a watch item in 2018.

Although the NASA EP Program began 2017 with an aggressive stance, it quickly stalled due to several factors. First, the Principal Advisor for Enterprise Protection announced his retirement after the first quarter of 2017, and his replacement was in place only after the start of the 4th quarter, leading to a leadership gap that may have been unavoidable but was nonetheless somewhat disruptive. Second, the Presidential Executive Order, *Strengthening the Cybersecurity of Federal Networks and Critical Infrastructure (May 11, 2017)*, necessitated the stand-up of a NASA "Tiger Team" to provide a very broad, comprehensive response to the White House on a very demanding timeline. This NASA Tiger Team was constituted with all available talent, including the use of scant resources that were otherwise dedicated to the EP Program. Third, NASA has received a number of reports from the NASA OIG that audit many elements of Enterprise Protection (e.g., cybersecurity, governance for mission and institutional IT systems), and NASA has been challenged to address the findings, some of which have repeated over several years.

It was apparent to the ASAP that NASA's concepts of Enterprise Protection are maturing. For example, the external pressure of the Presidential Executive Order ultimately created a much-needed focus on the risk management of the entire NASA enterprise, and NASA has now generated a comprehensive framework for future implementation of risk reduction. In addition, NASA is now working on an interim directive related to Enterprise Protection for the Agency and is developing a concept for a type of centralized security center designed to coordinate with other agencies on threat-based, cybersecurity issues.

As much as NASA has advanced its thinking on enterprise risk reduction for physical, corporate, and mission layers, it still requires governance, language, rule sets, budget alignments, clarity of authorities, and much more to actually achieve a sea change in risk-reducing behaviors across the enterprise. The ASAP senses that there are "great ideas" from NASA management on how to coordinate between disparate Centers and mission programs—some of which we noted in our 2016 report—but there is little evidence of comprehensive improvement plans that are designed to reduce risk. For example, the NASA OIG Report IG-18-002, *NASA'S Efforts To Improve The Agency's Information Technology*

Governance (Oct 19, 2017), documented NASA's governance entities and their respective responsibilities for budget, authorities, policy, security, and the like, but made no mention at all of the Agency's new EP Position nor the related EP Board. We were impressed with the enterprise risk reduction framework that NASA provided to the Executive Branch in August 2017, but it may be time to pause, redefine, and realign disparate enterprise protection governance activities—EP Office, OCIO, Center Directors, Mission/Center Project Managers/Chief Information Officers, Facility Operations, related Boards/Councils, etc.—to make the framework a reality that produces results. Any EP Program will be effective only if the entire Agency embraces it fully.

In the 2016 report, the ASAP mentioned concerns that the EP Principle Advisor and the EP Program was not a NASA program in the traditional sense, and that the EP Program needed to receive support and resources to wield influence within the Agency in the face of complacent security culture and ineffective integration. Although we have not seen sufficient evidence of a broadly supported EP Program, the Principal Advisor and the EP Program did make progress in addressing our very specific concern—implementing a policy that ensures that appropriate security clearances levels are attained and maintained for those personnel who have a role in managing enterprise risk, including the appropriate program managers. In 2016, we formulated a recommendation on this topic.

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

The ASAP received a progress report late in 2017 about NASA's improved security clearance metrics. The report indicated that the management of security clearances has the appropriate attention at the most senior leadership level, and that some top-down discipline has been instilled in NASA's processes for defining, implementing, and monitoring the necessary match between security requirements and personnel positions.

In summary, while the Panel was initially impressed with the overall vision of the EP Program, NASA's efforts do not seem to be integrated across the enterprise. Our observations are generally consistent with both the recent NASA OIG Federal Information Security Management Act (FISMA) Evaluation (Nov 6, 2017) and recent NASA OIG Audits, which repeatedly state that NASA has done a fairly good job of self-assessment but lacks cohesive, integrated, executable improvement plans. In 2018, we will watch with interest to see how NASA intends to use its new, comprehensive framework to reduce risk across the enterprise.

VIII. Summary

Ten topic areas, highlighted in this report, are summarized in the following table. They have been broken out to focus attention on individual issues that the Panel feels are worthy of note.

Topics	2017 Assessment
Impact of Continuing Resolution Funding	The Panel continues to be concerned with the continued use of partial year CRs, which add complexity and uncertainty to program management and execution, and detract from the requisite focus on safety and mission assurance.
Micrometeoroids and Orbital Debris	The potential for damage from MMOD is a major and increasing risk factor for every human space flight program. Serious improvements are needed in space situational awareness, space traffic management, and efforts to prevent the generation of new debris while reducing hazards posed by existing debris.
Human Space Flight Mishap Investigation Planning	The Panel has recommended that the language in the NASA Authorization Act of 2005 requiring a Presidential Commission investigation in all cases involving loss of flight crew as well as cases involving loss of vehicle, be reviewed and modified. The goal should be to have an independent review by qualified individuals, including NASA participation, in a thorough but expeditious manner.
Enterprise Protection	While the Panel was initially impressed with the overall vision of the EP Program, NASA's efforts do not seem to be integrated across the enterprise. NASA has done a fairly good job of self-assessment but lacks cohesive, integrated, executable improvement plans.
Commercial Crew Technical and Schedule Challenges	The current planning dates for the first crewed missions would allow NASA to maintain uninterrupted access to ISS. However, based on the quantity, significance, and associated uncertainty of work remaining for both providers, future schedule slips could easily consume all remaining margin. There are several major qualification and flight test events that historically are schedule drivers or could reveal the need for additional work. Space X is also still working the redesign and qualification of the COPV helium tanks for the Falcon 9.
Deep Space Exploration	NASA has defined the DSG as a flexible architecture capable of partnering with both industry and international partners to carry out exploration technology and operational risk mitigation in cislunar space. Given the recent direction to return to the lunar surface, the Panel is concerned that without additional resources to accomplish this new task, NASA's ability to conduct a robust risk mitigation program will be in jeopardy. Adequate resources should be provided to ensure proper program content, testing, and milestones related to risk reduction for future Mars missions.
Exploration Systems Development—Program Schedule Impact on Safety	In 2015, the Panel expressed concern that NASA was making changes to the Orion Test and Verification plan primarily to maintain schedule and did not assess the cumulative risk associated with those changes. However, currently we continue to see NASA's commitment to "not cut technical content to hold schedule." Yet, the upcoming program development activity is highly complex and involves the testing of huge pieces of hardware that continues to put pressure on the certification program, so this remains a watch item.
Exploration System Development—Launch Gap	The needed modification of the MLP to accommodate the SLS when fitted with the EUS would cause an approximate 33-month gap between EM-1 and EM-2, giving rise to a potential safety problem from the deterioration in both the number and skill of the ground launch work force. This could be mitigated by the construction of a second MLP if initiated in the near term.
International Space Station Contingency Deorbit Planning	While ISS deorbit planning continues to make progress and a designated Project Manager has been established to coordinate required actions, several critical elements of preparing to safely deorbit the Station in the event of an emergency are still required. Much of this work is beyond NASA's control and must be accomplished by our Russian partner in order to have an emergency deorbit capability in place if needed.
Funding Adequacy for NASA Aircraft Management Information System	Adequate funding for NAMIS causing a large backlog in functional change requests was highlighted as a serious issue in last year's report. This year, NAMIS funding responsibility was assumed by NASA OCIO and the backlog, while still significant, has been reduced. Despite funding being aligned under the OCIO, some budgetary risk remains, as evidenced by the FY 2017 funding shortfall of approximately $300,000 (93 percent of original request). The NAMIS CCB is managing risk effectively at this time, but deeper budgetary cuts could jeopardize long-term NAMIS functionality.

Appendix A

Significant Incidents and Close Calls in Human Spaceflight

A Product of the JSC S&MA Flight Safety Office

Legend

- Loss of Crew
- Crew Injury/Illness and/or Loss of Vehicle or Mission
- Related or Recurring event

SR-71

Launch/Ground

STS-110 4/8/2002
STS-109 3/1/2002
STS-108 12/5/2001
Incorrect adjustments to the controller software resulted in SSME underperformance.
Crew: 7

STS-91 6/2/1998
Main engine pressure chamber sensor failed. If it occurred later, logic error may have triggered at RTLS.
Crew: 6

Soyuz TM-9 2/11/1990
DM insulation torn loose on ascent; contingency EVA repair.
Crew: 2

SRB Seal Events (1981-1996)

STS-51L (Challenger) 1/28/1986
SRB seal failure.
Crew: 7 **Loss of Crew**

Other SRB gas sealing anomalies: STS-2, 6, 41B, 41C, 41D, 51C, 51D, 51B, 51G, 51F, 51I, 51J, 61A, 61B, 61C, 42, 71, 70, 78

STS-51F 7/29/1985
Temperature sensor problems resulted in SSME1 shutdown at T+5:45.
Crew: 7 Abort To Orbit

Soyuz 18-1(18a) 4/5/1975
Electrical fault caused premature firing of half of the 2nd stage separation bolts, resulting in the inability to fire the remaining ones. Staging failure resulted in abort sequence being used at T=295 seconds.
Crew: 2 Loss of Vehicle/Mission

Apollo 13 4/11/1970
2nd stage center engine shutdown due to pogo oscillations.
Crew: 3

Apollo 12 11/14/1969
Lightning strike on ascent.
Crew: 3

Gemini 10 7/18/1966
1st stage oxidizer tank exploded at staging. No discernable effects. Nominal ascent.
Crew: 2

Progress M-12M (44P) 8/24/2011
Anomaly in fuel pressurization system led to shutdown of 3rd stage engine. Vehicle failed to reach orbit.
Crew: 0 Loss of Vehicle/Mission

STS-117 6/8/2007
Thermal blanket damage. EVA performed to repair damage.
Crew: 7

STS-114 5/26/2005
- Bird strike on External Tank.
- Loss of foam from External Tank PAL ramp.
- TPS gap filers protruding. Removed during third mission EVA.
- Missing O-ring resulted in ejection of one of two NSIs, compromising the ET forward separation bolt function and damaging secondary structure and a thermal blanket.

Crew: 7

STS-93 7/23/1999
- At T+5 a short on AC1 Phase A resulted in loss of SSME1 Controller A and SSME3 Controller B.
- SSME3 H_2 leak: early LOX depletion and shutdown.

Crew: 5

Ascent Debris

STS-124 5/31/2008
Pad 39-A flame trench suffered significant damage causing about 3,500 refractory bricks to be blown away from the flame trench wall.
Crew: 7

STS-95 10/29/1998
Drag chute door separated during launch and impacted main engine bell.
Crew: 7

Other significant ascent debris events have occurred on:
STS-116 and STS-125

Late Release Orbiter Tyvek Covers
STS-114, 115, 118, 119, 124, 126

STS-112 10/7/2002
T-0 umbilical issues resulted in none of the system A pyrotechnic charges firing.
Crew: 6

STS-61C 1/6/1986
System configuration errors resulted in inadvertent drain back of 14,000 lbs of LOX prelaunch, which would have resulted in a Trans-Atlantic Abort Landing.
Crew: 7

On-pad Abort Events (1984-1993)

STS-41D 6/26/1984
Following a pad abort, LH_2 leaked from SSME3, resulting in a fire at the base of the orbiter.
Crew: 6

Soyuz T-10-1 (T-10a) 9/26/1983
Pad booster fire/explosion. Capsule Escape System used.
Crew: 2 Loss of Vehicle/Mission

Other On-pad Abort Events:
STS-51F, STS-55, STS-51, STS-68.

STS-1 4/12/1981
SRB ignition pressure wave caused TPS and structural damage.
Crew: 2

Apollo 1 (AS-204) 1/27/1967
Crew cabin fire (electrical short + high pressure O_2 atmosphere).
Crew: 3 **Loss of Crew**

Gemini 6 12/12/1965
Main engine shutdown. Booster left unsecured on pad. Crew elected not to eject. Launched 3 days later.
Crew: 2

Suborbital Flights

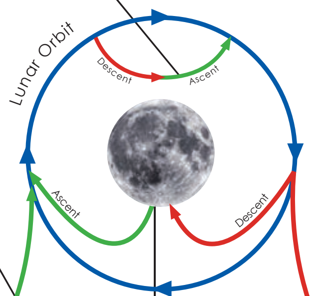
Ascent / Entry

X-153-65-97 11/15/1967
Electrical short and crew error led to loss of control at 230,000 feet. First U.S. spaceflight fatality.
Crew: 1 **Loss of Crew**

SpaceShipOne, 16P 9/29/2004
Uncommanded vehicle roll. Control regained prior to apogee.
Crew: 1

SpaceShipOne, 14P 5/13/2004
Flight computer unreponsive. Recovered by rebooting.
Crew: 1

Lunar Orbit



Outbound / Earth Return

EVA Incidents Summary (1965-2014)

13 EVAs resulted in crew injury:
Gemini 10, Apollo 17, Salyut 7 PE-1, Salyut 7 VE-3, STS-61-B EVAs 1&2, STS-37, Mir PE-9, STS-63, STS-97/4A, STS-100/6A EVAs 1&2, STS-134/ULF6

See the Significant Incidents in EVA Operations Graphic for more details. (spaceflight.nasa.gov/outreach/readersroom.html)

Apollo 10 5/22/1969
Switch misconfiguration resulted in lunar module control problems.
Crew: 2

Apollo 14 1/31/1971
Multiple failed docking attempts. Contingency procedures developed to mitigate risk of recurring docking anomaly. Docking successful.
Crew: 3

Apollo 13 4/13/1970
Explosion due to electrical short. Loss of O_2 and EPS.
Crew: 3 Loss of Mission

Apollo 11 7/21/1969
Engine arm circuit breaker knob broke off. Circuit breaker successfully reset allowing ascent.
Crew: 2

Medical Evacuation
Mir EO-2, 1987, C
One replaced
medical condi
Salyut 7, 1985, Cr
One returned v
due to medica
Salyut 5, 8/25/197
Early return of c
effects from sus
gases in space

Earth Orbit

ISS Increment 38 12/11/2013
ITCS configuration errors resulted in near freezing and potential rupture of water-to-ammonia heat exchanger.
Crew: 6

Soyuz TMA-18 (22S) 9/23/2010
First attempt to separate from ISS failed; ISS crew succeeded in bypassing faulty sensor.
Crew: Soyuz 3, ISS 3

ISS, Increment 17 4/30/2008
Freon 218 leaked from SM AC.
Crew: 3

ISS Increment 15 6/10-6/18/2007
Power switch failures caused loss of ISS propulsive attitude control capability.
Crew: 10

ISS, Increment 13 8/2006
Triol coolant leak in SM.
Crew: 3

ISS, Increment 10 2/2005
Potential acid preservative aerosol escape from Russian urinal.
Crew: 2

ISS, Increment 5&6 mid-2002-2/03
Formaldehyde periodically exceeded long-term limits.
Crew: 3-10

ISS, Increment 2-4 4/2001-3/2002
Freon 218 leaked from SM AC.
Crew: 3

ISS, Increment 4 2/2002
MetOx regeneration caused noxious air.
Crew: 3

ISS 8/2001
Extrememly high methanol levels in FGB air sample.
Crew: 3

STS-104 7/2001
EMU battery leaked hazardous KOH. Discovered during EMU checkout.
Crew: 5

ISS Increment 2 4/24/2001
Failure of all U.S. command and control computers on ISS.
Crew: 10

STS-99 2/2000
High bacterial count in postflight sample after GIRA installed to removed iodine.
Crew: 6

ISS, Flight 2A.1 5/1999
Crew sickened in FGB; likely a result of high localized CO_2 levels due to poor ventilation.
Crew: 7

STS-95 10/29/1998
Preflight sterilization process chemically altered the Low Iodine Residual System resulting in contaminated drinking water.
Crew: 7

STS-87 11/21/1997
Spartan satellite deployed without proper activation. Recapture with RMS unsuccessful. Later captured by EVA crew.
Crew: 6

Mir 7/17/1997
Accidental unplugging of computer power cable led to loss of attitude control and loss of power.
Crew: 3

STS-83 4/6/1997
Failure of fuel cell number 2 resulted in MDF being declared. The 15-day mission was shortened to 3 days.
Crew: 7 Minimum Duration Flight
Loss of Mission

STS-51 9/12/1993
Both port-side primary and secondary SUPER*ZIP explosive cords fired, resulting in containment tube failure and damage in the payload bay.
Crew: 5

STS-44 11/24/1991
Failure of IMU 2 caused MDF to be declared. 10-day mission shortened to 7 days.
Crew: 6 Minimum Duration Flight

STS-32 1/9/1990
Erroneous state vector up-linked to flight control system, causing immediate and unpredictable attitude control problems.
Crew: 3 Loss of Attitude Control

STS-9 12/8/1983
Two GPCs failed during reconfiguration for entry. One GPC could not be recovered.
Crew: 3

STS-2 11/12/1981
- Failure of fuel cell resulted in a MDF being declared.
- The fuel cell failure also resulted in hydrogen in the drinking water leading to crew dehydration.

Crew: 2 Mission Terminated

Soyuz 33 4/12/1979
Main engine anomaly caused final rendezvous abort.
Crew: 2 Loss of Mission

Soyuz 21 8/24/1976
Separation from Salyut failed; ground command succeeded in opening latches.
Crew: 2

Soyuz 1 4/23/1967
Failures in attitude control and electrical power systems resulted in a loss of mission. The launch of the intended docking target, Soyuz 2, was scrubbed.
Crew: 1 Loss of Mission

Gemini 8 3/16-3/17/1966
Stuck thruster caused loss of control and led to 1st U.S. emergency de-orbit.
Crew: 2 Emergency De-orbit

Mercury MA-9 5/16/1963
Electrical faults caused loss of some systems and need to perform manual entry. Also experienced high $PPCO_2$ levels in suit during entry operations.
Crew: 1 Manual Entry

Mir Collision Events (1994-1997)

Mir 6/25/1997
Progress M-34 collided with Mir. Spektr pressure shell ruptured. Spektr module isolated. Cables through hatchway impeded hatch closing.
Mir Crew: 3 Collision

Mir 8/30/1994
Progress M-24 collided with Mir during second docking attempt.
Mir Crew: 2 Collision

Mir 1/14/1994
Soyuz TM-17 collided twice with Mir during undocking.
Crew: Soyuz 2, Mir 3 Collision

Fire/Overheating (1971-2008)
ISS, 10/10/2008
ISS, 9/18/2006,
ISS, 3/2005, Cre

Mir*
Overheating BM
health-threaten
Crew: 2

Mir*
Chemical oxyg
(SFOG) failure
Crew: 5

Mir, 10/1994, C
STS-40, 6/1991,
STS-35, 12/1990
STS-28, 8/1989,
STS-6, 4/1983, C
Salyut 7, 9/198
Salyut 6, 1979,
Salyut 1, 6/197

*toxic byprodu

Docking Anomalies

STS-133
Experienced significant misalignment between orbiter a
post-capture free drift due to gravity-gradient-induced
Crew: 6

STS-130
Experienced significant misalignment between orbiter a
post-capture free drift due to gravity-gradient-induced
Crew: 6

Soyuz T-8
Loss of rendezvous antenna prevented docking.
Crew: Soyuz 3

Skylab 2
Multiple failed automatic docking attempts resulted in ma
Skylab.
Crew: 3

Soyuz 10
Automatic docking system failed. Manual docking with Saly
Crew: 3

Research Facility

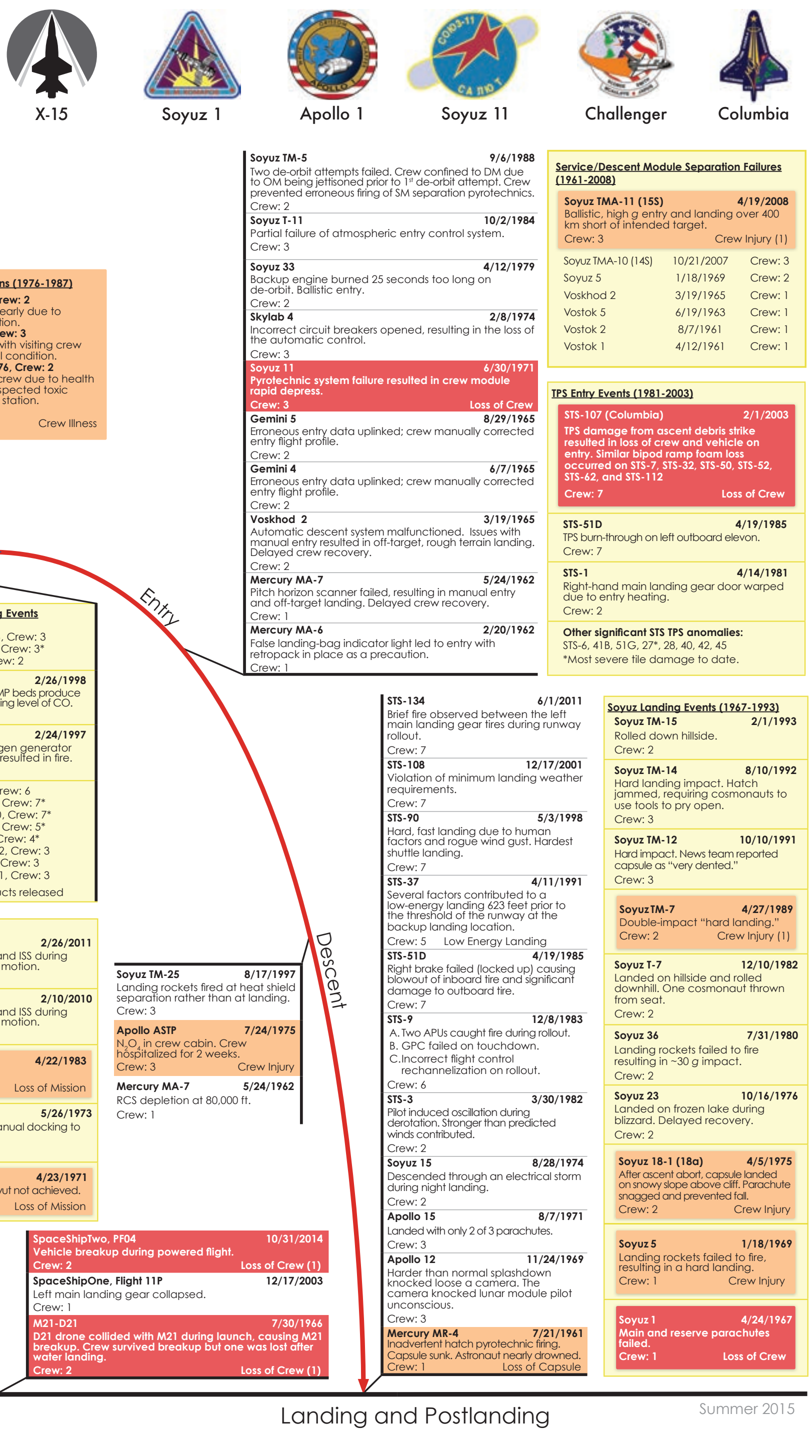
Altitude Chamber O_2 Fire - Soviet 3/23/1961
Alcohol wipe hit hot plate and started fire in oxygen-rich test chamber.
Crew: 1 **Loss of Crew**

Navy Chamber 11/17/1962
Fire started in a 100% oxygen environment at 5 psi. Four officers injured.
Crew: 4 Crew Injury (4)

Atmospheric Flights

Ascent / Cruise / Descent

SR-71 1/25/1966
Loss of control at high speed and altitude.
Crew: 2 **Loss of Crew (1)**



Abbreviations and Acronyms

AC	Air Conditioner
APU	Auxiliary Power Unit
BMP	Microimpurities Removal System (Russian)
CDRA	Carbon Dioxide Removal System
CMG	Control Management Gyroscope
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DM	Descent Module
EMU	Extravehicular Mobility Unit
EPS	Electrical Power System
EV	Extravehicular
FGB	Functional Cargo Block (Russian)
FSO	Flight Safety Office
GIRA	Galley Iodine Removal Assembly
GPC	General Purpose Computer
GPS	Global Positioning System
H_2	Hydrogen
IMU	Inertial Measurement Unit
ISS	International Space Station
ITCS	Internal Thermal Control System
KOH	Potassium Hydroxide
LH_2	Liquid Hydrogen
LOC	Loss of Crew
LOV	Loss of Vehicle
LOX	Liquid Oxygen
MDF	Minimum Duration Flight
MetOx	Metal Oxide
MMOD	Micro-Meteoroid Orbital Debris
N_2O_4	Nitrogen Tetroxide
NSI	NASA Standard Initiator
O_2	Oxygen
OM	Orbital Module
OSMA	Office of Safety & Mission Assurance
PAL	Protuberance Air Load
PASS	Primary Avionics Software System
$PPCO_2$	Partial Pressure of Carbon Dioxide
RCS	Reaction Control System/Subsystem
RMS	Remote Manipulator System
RTLS	Return to Launch Site
SFOG	Solid Fuel Oxygen Generator
S&MA	Safety & Mission Assurance
SM	Service Module
SRB	Solid Rocket Booster
SSME	Space Shuttle Main Engine
SSP	Space Shuttle Program
STS	Space Transportation System
TPS	Thermal Protection System
U.S.	United States

Visit the NASA Human Spaceflight Readers Room (http://spaceflight.nasa.gov/outreach/readersroom.html) for the latest version of the Significant Incidents and Close Calls in Human Spaceflight chart.

Contacts

Nigel Packham, Ph.D., NASA
Manager, JSC S&MA Flight Safety Office
Nigel.Packham-1@nasa.gov

William Stockton, SAIC
FSO Support Team Lead
William.W.Stockton@nasa.gov

Dennis Pate, SAIC
Assessments Specialist, FSO Support Team
Dennis.W.Pate@nasa.gov

The Significant Incidents and Close Calls in Human Spaceflight graphic is primarily focused on human spaceflight incidents occurring with a crew aboard a space vehicle. It includes suborbital, orbital, and lunar missions. Selected non-spaceflight and uncrewed events are included if they have strong relevance to human spaceflight. For instance, the loss of the uncrewed Progress 44P is included because it has launch vehicle commonalities with the crewed Soyuz missions. The altitude chamber oxygen fire in Russia preceded the U.S. Navy oxygen chamber fire and the Apollo 1 fire, which occurred under similar circumstances. The SR-71 accident is the highest and fastest vehicle breakup on record that was survivable, and it represents the demonstrated limit of crew survival with current technology. The SpaceShipTwo accident represents the loss of a suborbital space vehicle during flight testing.

This document is a work in progress. It is continually under review and frequently updated. Please direct comments and questions to the JSC S&MA Flight Safety Office.

Appendix B

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

2017 Recommendations[4]

2017-01-01

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

> **OPEN** NASA responded on 5/22/17, concurring with the recommendation. NASA stated that the Commercial Crew Program (CCP) providers are responsible for ensuring cost-effective system design, realization, operation, and technical management of the systems they are developing to meet a fixed-price contract. Through contract requirement, deliverables, and increased insight, CCP asserts the ability to verify and/or validate that SE&I principles are followed to assure the proper management of risks, requirements, interfaces, configuration, and technical data throughout the system life cycle. ASAP continues to monitor CCP progress in gathering evidence of SE&I practices throughout the development and certification process.

---

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

2017-02-01

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

> **OPEN** NASA responded on 8/29/17, concurring with the recommendation and provided a presentation at the 4th Quarterly Meeting of 2017. OSMA has prepared a survey of targeted SMA engineering disciplines, including System Safety, and will administer it from November 2017 through January 2018. After review and analysis of the system safety survey, OSMA will use the results to inform like activities in other SMA engineering disciplines. ASAP wants to be assured that OSMA has a mechanism to verify that the NASA safety policies, processes, and procedures are being followed to ensure employee safety, system safety, and program safety. The Panel will continue to monitor progress and the results of the system safety survey.

Open Recommendations from Prior Years

2016-04-01

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

> **OPEN** NASA responded on 1/17/17, concurring with the recommendation. NASA is establishing clearance requirements within the governance management system of the Enterprise Protection Program (EPP) and is reviewing all positions descriptions and compliances accordingly. The Panel was last briefed on the EPP in November 2017. Work is on-going. ASAP will continue to follow the progress of this action in 2018.

2015-05-02

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

OPEN NASA originally responded on 4/31/2016. The response stated NASA was reaching out to the Federal Aviation Administration (FAA) and the National Transportation Safety Board (NTSB) to jointly develop viable options to revise the Authorization language with today's systems in mind. The NASA Human Exploration and Operations Mission Directorate (HEOMD) reported at the 3rd Quarterly of 2016 that the effort was on-going and provided tentative language. NASA predicted they would have proposed language by end of the 2016.

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 (CPP). The ASAP provided a written response on September 8, 2017, followed by subsequent discussions and is awaiting NASA's formal response to the Panel's input. The Agency is currently reviewing the ASAP response.

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 NASA originally responded on 4/24/14. The Office of the Chief Health and Medical Officer (OCHMO) briefed the NASA implementation plan to the recommendations in the Institute of Medicine (IOM) Study to the ASAP on 10/28/14 at the 4th Quarterly ASAP meeting. The ASAP was complimentary of the plan and said in their response dated 11/17/14 that NASA should adopt the process as briefed. OCHMO had the action to get on the Agency PMC agenda to brief the implementation plan. Once complete and the associated decision memo has been signed, OCHMO was to develop the appropriate OCHMO Procedural Requirements. OCHMO briefed the Panel again at the 2nd Quarterly of 2016 on the plan for implementing recommendations from the IOM report "Health Standards for Long Duration and Exploration Spaceflight Ethics, Principles, Responsibilities and Decision Framework." The Panel had favorable response to report and is awaiting NASA policy and guidelines for implementation of these plans.

The ASAP received an update at the 3rd Quarterly Meeting of 2017. Progress has been made in policy and guidelines. Work is on-going and will continue into 2018.

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 NASA originally responded on 7/22/14 and updated response on 1/22/15. The Office of Safety and Mission Assurance (OSMA) presented at the 2nd Quarterly of 2016 and later met with ASAP Chair for input into updated policies. OSMA released an interim directive in September of 2016 to temporarily institute a formal process for risk acceptance procedure. A permanent policy establishing individual risk acceptance authorities, NPR 8000.4B, was released on 12/6/17, as this report was being finalized. Over the next reporting period, the ASAP will carefully monitor the training, promotion, implementation, and enforcement of this important policy change.

2012-01-02

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

OPEN NASA originally responded on 5/9/12. ASAP decided the recommendation would stay open until ISS has a timeline for implementing a deorbit plan and the deorbit plan is in place. HEOMD began working this action when assigned in 2012. There are many aspects to implementing the deorbit plan, including working with international partners. It is estimated that it will take 1–2 years to implement the plan after the schedule is determined. At the 2016 1st Quarterly, the current ISS Program Manager briefed the Panel on the status of the deorbit plan. In January 2016, the Russians had received direction to restart End-of-Life (EOL) production development. In March 2016, a Technical Interchange Meeting was held to move the EOL activities forward. The ISS briefing at the 3rd and 4th Quarterlies of 2016, showed further progress; however, the plan is still not complete. The ASAP received status updates during the four Quarterly Meetings of 2017. ISS has provided a timeline chart and made some forward progress with Russia. ISS will continue to brief the ASAP on a quarterly basis on the status of this recommendation in 2018.

Appendix C

Closure Rationale for Recommendation Closed in 2017

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 (vs. 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.

CLOSURE RATIONALE: The Panel received a briefing from NASA Chief Knowledge Officer at the second quarterly meeting of 2017, detailing the tools for sharing information. With the updates made to the Knowledge Management system, the ASAP closed this recommendation.

Aerospace Safety Advisory Panel

Dr. Patricia A. Sanders, Chair
Dr. James P. Bagian
Mr. John C. Frost
Lieutenant General Susan J. Helms, USAF (Ret.)
Captain Brent W. Jett, Jr., USN (Ret.)
Dr. Sandra H. Magnus
Dr. Donald P. McErlean
Dr. George C. Nield
Captain Christopher M. Saindon, USN (Ret.)

NP-2017-11-2493-HQ