AN UPDATE ON NASA COMMERCIAL CREW SYSTEMS DEVELOPMENT

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED FIFTEENTH CONGRESS

SECOND SESSION

JANUARY 17, 2018

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AN UPDATE ON NASA COMMERCIAL CREW SYSTEMS DEVELOPMENT

WEDNESDAY, JANUARY 17, 2018

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to call, at 10:08 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Brian Babin [Chairman of the Subcommittee] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

Congress of the United States
House of Representatives
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
2321 RAYBURN HOUSE OFFICE BUILDING
WASHINGTON, DC 20515-6301
(202) 225-6371
www.science.house.gov

An Update on NASA Commercial Crew Systems Development

Wednesday, January 17, 2018
10:00 a.m.
2318 Rayburn House Office Building

Witnesses

Mr. William Gerstenmaier, Associate Administrator, Human Exploration and Operations Directorate, NASA

Mr. John Mulholland, Vice President and Program Manager for Commercial Programs, Boeing Space Exploration

Dr. Hans Koenigsmann, Vice President of Build and Flight Reliability, SpaceX

Ms. Cristina Chaplain, Director, Acquisition and Sourcing Management, U.S. Government Accountability Office

Dr. Patricia Sanders, Chair, NASA Aerospace Safety Advisory Panel

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE

Charter

TO:	Members, Committee on Science, Space, and Technology
FROM:	Majority Staff, Committee on Science, Space, and Technology
DATE:	January 17th, 2018
SUBJECT:	Space Subcommittee Hearing: "An Update on NASA Commercial Crew Systems Development"

On Wednesday, January 17 at 10:00 a.m. in Room 2318 of the Rayburn House Office Building, the Committee on Science, Space, and Technology, Subcommittee on Space, will hold a hearing titled, "An Update on NASA Commercial Crew Systems Development."

Hearing Purpose

The purpose of the hearing is to examine the development of NASA's two commercial crew systems, being built by Boeing and SpaceX, to service the International Space Station.

Witnesses

- **Mr. William Gerstenmaier**, Associate Administrator, Human Exploration and Operations Directorate, NASA
- **Mr. John Mulholland**, Vice President and Program Manager for Commercial Programs, Boeing Space Exploration
- **Dr. Hans Koenigsmann**, Vice President of Build and Flight Reliability, SpaceX
- **Ms. Cristina Chaplain**, Director, Acquisition and Sourcing Management, U.S. Government Accountability Office
- **Dr. Patricia Sanders**, Chair, NASA Aerospace Safety Advisory Panel

Staff Contact

For questions related to the hearing, please contact Mr. Tom Hammond, Staff Director, Space Subcommittee, Mr. G. Ryan Faith, Professional Staff Member, Space Subcommittee, or Ms. Sara Ratliff, Policy Assistant, Space Subcommittee, at 202-225-6371.

Chairman BABIN. Good morning. The Subcommittee on Space will come to order. Without objection, the Chair is authorized to declare recesses of the Subcommittee at any time. Welcome to today's hearing titled, "An Update on NASA Commercial Crew Systems Development. I would like to recognize myself for five minutes for an opening statement."

The next few years will be busy for space exploration. NASA will be busy not only launching new systems, but they will be developing new business models, new contracting mechanisms and new ways of approaching every facet of the challenge of expanding human presence beyond low-Earth orbit.

Engaging with commercial partners to meet exploration needs is part of that broader effort. I'm very eager to see how we can partner with the private sector to advance NASA's goals. NASA's Commercial Crew Program is part of that effort. And as we assess the merits of this new approach, we must also recognize the hazards of such partnerships. Without diligent oversight by NASA and Congress, these programs could simply end up being corporate welfare and bad deals for the taxpayer.

This Commercial Crew Program builds on the commercial cargo program and offers new insights about how government and industry can work together on key tasks. Perhaps even more importantly, this program is a key part of the bigger, broader effort to industrialize low-Earth orbit and transition the International Space Station to a new operating model in the next decade.

But instead of looking forward and tackling the economic self-sufficiency and operation of the ISS, we are here today looking at not one but two companies that are behind schedule, may not meet safety and reliability requirements, and could even slip into cost overruns. Rather than being able to praise the success of a new approach to business, we are now confronted with the news that the certification won't happen until at least 2019.

This situation gets even worse when we look at the safety and reliability concerns surrounding these two new systems. Both programs suffer from shared and individual issues concerning reliability and safety. The risk that these companies cannot meet their deadlines or safety requirements increases the risk that the ISS cannot be successfully or gracefully transitioned in the middle of next decade. Increasing risks to ISS transition in turn, increase risk to human exploration programs in general. Further, they decrease the collective appetite for the kind of innovative partnerships that will be vital to a host of future NASA exploration and science missions.

Both this hearing and last November's hearing on SLS and Orion get to matters of risk. What is the risk that NASA will be unable to meet its long-term goals of expanding permanent human presence beyond low-Earth orbit? Each program features cost, schedule, and performance risks. Those programmatic risks translate into risks to the overall exploration architecture.

Both companies are making progress but certainly not at the rate that was expected and not without significant challenges to safety and reliability. In order to remedy these problems, NASA may seek additional funding or accept significant risks. Neither of those op-

tions is viable. As I said at our recent hearing on SLS and Orion, NASA and the contractors have to execute.

I would like to thank our witnesses for their testimony and look forward to getting a better understanding of where we are and what our prospects look like going forward.

[The prepared statement of Chairman Babin follows:]

COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Lamar Smith, Chairman

For Immediate Release
January 17, 2018

Media Contacts: Thea McDonald, Brandon VerVelde
(202) 225-637

Statement by Chairman Brian Babin (R-Texas)

An Update on NASA Commercial Crew Systems Development

Chairman Babin: The next few years will be busy for space exploration. NASA will be busy not only launching new systems, but they will be developing new business models, new contracting mechanisms and new ways of approaching every facet of the challenge of expanding "human presence beyond low-Earth orbit."

Engaging with commercial partners to meet exploration needs is part of that broader effort. I am eager to see how we can partner with the private sector to advance NASA's goals. NASA's commercial crew program is part of that effort. As we assess the merits of this new approach, we must also recognize the hazards of such partnerships. Without diligent oversight by NASA and Congress, these programs could simply end up being corporate welfare and bad deals for the taxpayer.

This commercial crew program builds on the commercial cargo program and offers new insights about how government and industry can work together on key tasks. Perhaps even more importantly, this program is a key part of the bigger, broader effort to industrialize low-Earth orbit and transition the International Space Station (ISS) to a new operating model in the next decade.

But instead of looking forward and tackling the economic self-sufficiency and operation of the ISS, we are here today looking at not one, but two companies that are behind schedule, may not meet safety and reliability requirements and could even slip into cost overruns. Rather than being able to praise the success of a new approach to business, we are now confronted with the news that the certification won't happen until at least 2019.

This situation gets even worse when we look at the safety and reliability concerns surrounding these two new systems. Both programs suffer from shared and individual issues concerning reliability and safety.

The risk that these companies cannot meet their deadlines or safety requirements increases the risk that the ISS cannot be successfully or gracefully transitioned in the middle of next decade. Increasing risks to ISS transition in turn, increase risk to human exploration programs in general. Further, they decrease the collective appetite for the

kind of innovative partnerships that will be vital to a host of future NASA exploration and science missions.

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Both companies are making progress, but certainly not at the rate that was expected, and not without significant challenges to safety and reliability. In order to remedy these problems, NASA may seek additional funding or accept significant risks. Neither of those options is viable.

As I said at our recent hearing on SLS and Orion, NASA and the contractors have to execute.

I would like to thank our witnesses for their testimony and look forward to getting a better understanding of where we are and what our prospects look like going forward.

###

Chairman BABIN. And now I would like to recognize the Ranking Member, the gentleman from California, for an opening statement.

Mr. BERA. Thank you, Mr. Chairman, and thank you for having this timely hearing and thank you to the witnesses.

You know, I represent a district in California, so I have these five to six hour flights across the country. And a couple weeks ago— I'll download a movie occasionally to watch on that flight. And I downloaded Apollo 13 to watch on the flight. Obviously, I think everyone in this room has seen that movie, but it's a great movie if you haven't seen it. But what it does suggest is the importance of safety in commercial crew launches. And you know, that was almost 50 years ago and just watching the importance of safety watching how those of us at NASA at the time back home improvising, trying to figure things out, using slide rules that might have been an over-dramatization, but they were using slide rules. And fast-forward to where we are today and think about the computing capabilities that we have and everything else. But it still doesn't mitigate the danger when you're sending human beings hundreds of thousands of miles away from the earth, particularly as we start to think about going further and further and the importance of safety. And regardless of everything that we do to mitigate things, the unexpected potentially can always happen. And you know, as we think about renewing our commercial crew capabilities here domestically, partnering with the commercial sector, safety is paramount and obviously the balance of meeting deadlines and goals and balancing that with safety.

I think the other important part as we start to get back into commercial crew capabilities here domestically in the United States, I do think we're taking the right approach partnering with the commercial sector with NASA. It's certainly in the lead looking at certification and everything else, but also having redundancy, having two companies that potentially give us that capability because again, you never know when something unexpected potentially happens.

I think for national pride, also allowing the United States domestically not to have to rely on another nation certainly is something that we think about.

And then we don't know what the 21st century in space is going to look like. Certainly you see more commercial interests, thinking about building habitats up there. You see folks talk about space tourism, et cetera. So again, as the commercial sector partners with our agencies, I think this is incredibly important.

With regards to today's hearing, I'm very interested in looking at and getting information on safety first; within that context, the safety driving the timeline as opposed to timeline driving safety; and then, really just curious about what those next steps are. If we are unable to hit some of the goals, my understanding is in the fall of this year, the hope is to do some unmanned tests, toward the end of 2018 to try to do some manned tests, and then to start the certification process in 2019. So I'd be curious again to hear from our witnesses and get some sense of how we're going to balance these competing interests but again leading with safety and then hitting our timeline goal.

So Mr. Chairman, thank you for another great hearing, and I look forward to hearing from our witnesses.

[The prepared statement of Mr. Bera follows:]

OPENING STATEMENT
Ranking Member Ami Bera (D-CA)
of the Subcommittee on Space

House Committee on Science, Space, and Technology
Subcommittee on Space
"An Update on NASA Commercial Crew Systems Development"
January 17, 2018

Good morning, and welcome to our distinguished panel of witnesses. Thank you Mr. Chairman for holding this hearing to receive an update on NASA's commercial crew systems development activities. Today, we are focusing on low-Earth orbit and the transition to a new model in which industry, in partnership with NASA, is developing commercial human spaceflight transportation services to provide NASA with crew transportation to and from the International Space Station.

Since being awarded firm-fixed-price contracts in 2014 for the development of commercial crew systems, Boeing and SpaceX have made measurable progress towards the goal of conducting uncrewed and crewed test flights. Those test flight demonstrations are critical before NASA can certify the systems' safety. Mr. Chairman, while Boeing's and SpaceX's crew systems take advantage of the nation's important human spaceflight heritage, both providers' capsules, ground systems, and even space suits will feature innovations that advance our nation's leadership in human spaceflight. In addition, the knowledge acquired from the Commercial Crew Program's partnerships can inform how NASA structures future partnerships, such as those that may support human exploration beyond low-Earth orbit.

As excited as I am about the future of commercial crew and commercial space activities, let me be clear. The development of new human-rated spacecraft is not easy and carries significant risk. There are stringent requirements for both human-rating and ISS proximity operations that must be met. NASA needs to assess whether the providers' approaches to meeting these requirements are acceptable, or if not, whether it will accept additional risks.

There is much anticipation for commercial crew activities as the U.S. looks to end its reliance on Russia as the sole means to transport NASA crews to and from the ISS, establish commercial human spaceflight services that may eventually support future commercial activities in low-Earth orbit, and allow NASA to focus its efforts on the human exploration of deep space. These goals will not be realized without the confidence that such systems are safe. Decisions that jeopardize safety in an effort to meet schedules typically do not end well. That painful lesson was learned from the *Challenger* and *Columbia* Space Shuttle accidents.

In its recently released 2017 Annual Report, the Congressionally-chartered Aerospace Safety Advisory Panel, which is represented here today, stated, "*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 those platforms for human space flight that should be based on a strong foundation of test and engineering data.*"

So, I hope that today's hearing will provide us with the opportunity to examine important issues regarding the development and status of commercial crew systems including:

- How NASA will ensure that commercial crew development is not subject to "schedule pressure" that could jeopardize crew safety;
- How NASA will ensure continued U.S. access to the ISS if commercial crew providers are delayed in achieving certification; and
- What steps NASA and the commercial providers are taking to minimize the risk to crews flying on these new spacecraft, as called for by the Columbia Accident Investigation Board.

In closing, I look forward to today's testimony and I yield back.

Chairman BABIN. Absolutely. Thank you, Mr. Bera. I really feel old this morning because I used to use a slide rule when I was in college. And I saw that movie again for about the third time a couple of weeks ago.

Okay. I'd like to now recognize the Chairman of our Full Committee, Mr. Smith from Texas.

Chairman SMITH. Thank you, Mr. Chairman. The goal of the Commercial Crew Program was to develop a faster, more cost-effective way to procure space transportation services without sacrificing safety or reliability. The intent was to leverage the lessons learned and the investments made in the commercial cargo program.

At the outset, there was hope that contractor funding would decrease the development costs to NASA and the taxpayer and that this would justify the contractors keeping the intellectual property derived from federal funding. There was also an assumption that the contractors would find other customers, improving economies of scale, which would then lead to lower launch prices for NASA. Finally, there was a presumption that contractors could deliver systems faster if there was less government oversight.

Today's hearing is a great opportunity to evaluate whether the program is living up to those goals. Have the contractors funded development costs? If so, how much? If not, why not? And should the government retain the intellectual property? Previous hearings held by this committee indicated that NASA is funding 90 percent or more of the costs. Has this changed?

Are the contractors finding other customers to offset NASA operational costs? The commercial cargo program created two separate Delta-2 class launch vehicles that have certainly found customers outside NASA. However, the costs to NASA under the second commercial resupply services contract went up, not down.

Should we expect costs to grow rather than shrink under the Commercial Crew Program as well? Has the Commercial Crew Program maintained its planned schedule? Are there appropriate incentives built into the contracts to maintain the schedule and penalize delays?

This hearing offers us the opportunity to reflect on the status of the program and seek answers to these questions. A lot has happened in the last few years. The program is making significant progress. However, as we will hear from the witnesses, there have been challenges. The Government Accountability Office reported last February that the neither Boeing nor SpaceX would be able to certify their systems in 2017.

That GAO report and the recently released Annual Report of the Aerospace Safety Advisory Panel both warned that certification is likely to slide even further to 2019. This was confirmed just last week when we were formally notified that SpaceX's first launch would be delayed again.

Further reports from the GAO, ASAP, and IG and others point out that neither company may be able to meet safety requirements. The recently released annual report from the Aerospace Safety Advisory Panel states it appears that neither provider will be able to achieve a no worse than one in 500 chance of losing a crew and

will be challenged to meet the overall mission requirement of one in 200, based on capsule design alone.

Meanwhile, as schedules slip, we continue to pay Russia $80 million per seat to take our astronauts to the ISS. This not only creates additional budget pressure on the agency, it hinders full utilization of the ISS, and ultimately complicates future exploration plans. With the end of the ISS on the horizon, the clock is ticking on maximizing the return on the taxpayer's investment. The longer we wait for the Commercial Crew Program, the less we can accomplish on ISS.

Other programs at NASA, including SLS and Orion and the James Webb Space Telescope also face significant delays, cost overruns and challenges.

The taxpayers and Congress have neither infinite budgets nor infinite patience. Foreseeable delays, predictable overruns and performance lapses all have real consequences. Contractors should not assume that the taxpayers and Congress will continue to tolerate this.

NASA and its contractors must restore American confidence in their ability to deliver safe, cost-effective leadership in space. This Committee has strongly supported the Commercial Crew Program and consistently advocated for full funding. That support continues, but the contractors need to deliver safe, reliable systems on budget and on schedule.

Thank you, Mr. Chairman. I yield back

[The prepared statement of Chairman Smith follows:]

COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Lamar Smith, Chairman

For Immediate Release
January 17, 2018

Media Contacts: Thea McDonald, Brandon VerVelde
(202) 225-6371

Statement by Chairman Lamar Smith (R-Texas)

An Update on NASA Commercial Crew Systems Development

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Further, reports from the GAO, ASAP, the inspector general and others point out that neither company may be able to meet safety requirements. The recently released annual report from the Aerospace Safety Advisory Panel states that it appears that neither provider will be able to achieve one in 500 for ascent/entry and will be challenged to meet the overall mission requirement of one in 200, based on capsule design alone.

Meanwhile, as schedules slip, we continue to pay Russia $80 million per seat to take our astronauts to the International Space Station (ISS). This not only creates additional budget pressure on the agency, it hinders full utilization of the ISS and ultimately complicates future exploration plans. With the end of the ISS on the horizon, the clock is ticking on maximizing the return on the taxpayer's investment. The longer we wait for the commercial crew program, the less we can accomplish on ISS.

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NASA and its contractors must restore our American confidence in their ability to deliver safe, cost-effective leadership in space. This committee has strongly supported the commercial crew program and consistently advocated for full funding. That support continues, but the contractors need to deliver safe, reliable systems on budget and on schedule.

###

Chairman BABIN. Yes, sir. Thank you. Thank you very much. And I'd like to now recognize the Ranking Member of the Full Committee, the gentlewoman from Texas, Ms. Johnson.

Ms. JOHNSON. Thank you very much, Mr. Chairman, and good morning and welcome to our witnesses.

Since the last Space Shuttle flight in 2011, the U.S. has lacked a domestic human spaceflight capability and has relied on Russian crew transportation services to transport NASA crew to and from the International Space Station. That arrangement has proved to be very durable in spite of geopolitical tensions back here on Earth. However, it is no substitute for U.S. crew transfer capabilities.

This morning's hearing will provide us, hopefully, with update on the status of NASA's and the industry's efforts to reestablish a domestic capability for launching our astronauts to the space station.

NASA's two Commercial Crew Program providers, Boeing and SpaceX, are working toward the goal of conducting test flights, first without crew onboard and later, of course, with crew. If these flight tests are successful, the current schedule would have NASA certify the two systems for operational missions sometime in 2019.

As we have discussed on numerous occasions in this Subcommittee, getting to this stage of the Commercial Crew Program has really not been easy. Our witnesses from the Aerospace Safety Advisory Panel and the Government Accountability Office will no doubt attest to that point. And the coming end of the availability of the Soyuz seats adds the risk of unhealthy schedule pressure to the other challenges facing the program.

Yet, despite the prospect of our access to seats on the Soyuz coming to an end next year, NASA and the two companies cannot afford to cut corners in attempting to prevent a potential gap in U.S. access to the International Space Station. Because, Mr. Chairman, if this is not to be sustainable, the end result of the Commercial Crew program must be safe and a safe commercial crew transportation system for all astronauts.

Next week NASA will commemorate the astronauts who died in the Columbia, Challenger, and Apollo I accidents as well as other NASA pilots and employees who lost their lives in the pursuit of space exploration. We cannot forget their sacrifices, even as we blaze new trails in space.

As the NASA Transition Authorization Act of 2017, "consistent with the findings and recommendations of the Columbia Accident Investigation Board, the Administration shall ensure that safety and the minimization of the probability of loss of crew are critical priorities of the Commercial Crew Program."

I hope that we will have a robust discussion at today's hearing on how NASA and its providers will ensure that planned commercial crew transportation systems are safe enough for our astronauts to fly in, what the challenges are to achieve that level of safety, and what safeguards the ASAP and GAO would recommend.

Thank you, Mr. Chairman, for holding the hearing. I look forward to hearing our witnesses, and I yield back.

[The prepared statement of Ms. Johnson follows:]

OPENING STATEMENT
Ranking Member Eddie Bernice Johnson (D-TX)

House Committee on Science, Space, and Technology
Subcommittee on Space
"An Update on NASA Commercial Crew Systems Development"
January 17, 2018

Good morning, and welcome to our witnesses. Since the last Space Shuttle flight in 2011, the U.S. has lacked a domestic human spaceflight capability and has relied on Russian crew transportation services to transport NASA crew to and from the International Space Station. That arrangement has proved to be very durable in spite of geopolitical tensions back here on Earth. However, it is no substitute for a U.S. crew transfer capability. This morning's hearing will provide us with update on the status of NASA's and industry's efforts to reestablish a domestic capability for launching our astronauts to the ISS.

NASA's two Commercial Crew Program providers, Boeing and SpaceX, are working towards the goal of conducting test flights, first without crew onboard and later with crew. If these flight tests are successful, the current schedule would have NASA certify the two systems for operational missions sometime in 2019. As we have discussed on numerous occasions in this Subcommittee, getting to this stage of the Commercial Crew Program has not been easy. Our witnesses from the Aerospace Safety Advisory Panel (ASAP) and the Government Accountability Office (GAO) will no doubt attest to that point. And the upcoming end to the availability of Soyuz seats adds the risk of unhealthy schedule pressure to the other challenges facing the program.

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As the NASA Transition Authorization Act of 2017 states: "*consistent with the findings and recommendations of the Columbia Accident Investigation Board, the Administration shall ensure that safety and the minimization of the probability of loss of crew are the critical priorities of the Commercial Crew Program*". I hope that we will have a robust discussion at today's hearing on how NASA and its providers will ensure that planned commercial crew transportation systems are safe enough for our astronauts to fly in, what the challenges are to achieving that level of safety, and what safeguards the ASAP and GAO would recommend.

Thank you, Mr. Chairman. I look forward to hearing from our witnesses, and I yield back.

Chairman BABIN. Yes, ma'am. Thank you very much. Now I'd like to introduce our witnesses that we are going to hear from today. The first witness today is Mr. Bill Gerstenmaier, Associate Administrator of Human Exploration and Operations Directorate at NASA. Mr. Gerstenmaier began his NASA career in 1977 performing aeronautical research and has managed NASA's human spaceflight portfolio since 2011. He received a Bachelor of Science in aeronautical engineering from Perdue University, and a Master of Science degree in mechanical engineering from the University of Toledo. Welcome.

Our second witness today is Mr. John Mulholland, vice president and program manager for Commercial Programs at Boeing. Prior to this, Mr. Mulholland served as the Vice President and Program Manager for the Boeing Space Shuttle Program. He was also the program director and chief engineer for the Boeing Space Shuttle Orbiter Team. Mr. Mulholland received both a Bachelor of Science in chemical engineering and a master's degree in mechanical engineering from New Mexico State University. Welcome.

Our third witness today is Dr. Hans Koenigsmann, the Vice President of Build and Flight Reliability at SpaceX. He has more than 25 years of experience designing, developing, and building complex avionics and guidance, navigation, and control systems for launch vehicles of satellites. Dr. Koenigsmann received a master's of science in aerospace engineering from the Technical University of Berlin and a Ph.D. in aerospace engineering and production from the University of Bremen. Welcome.

Our fourth witness today is Ms. Cristina Chaplain, Director of Acquisition of Sourcing Management at the U.S. Government Accountability Office. Among other topics, Ms. Chaplain has led reviews on the ISS, Space Launch System, and Orion crew capsule as well as commercial cargo and crew projects at NASA. Mrs. Chaplain received a bachelor's degree in international relations from Boston University and a master's degree in journalism from Columbia University. Welcome to you.

Our final witness today is Dr. Patricia Sanders, Chair of the NASA Aerospace Safety Advisory Panel, ASAP, and she previously served as Executive Director of the Missile Defense Agency, as well as Director of Tests, Systems Engineering, and Evaluation at the Office of the Secretary of Defense. She received her Ph.D. in mathematics from Wayne State University in Detroit, Michigan. And welcome to you, Dr. Sanders.

I would like to now recognize Mr. Gerstenmaier for five minutes to present his testimony. Mr. Gerstenmaier?

TESTIMONY OF MR. WILLIAM GERSTENMAIER,
ASSOCIATE ADMINISTRATOR,
HUMAN EXPLORATION AND OPERATIONS DIRECTORATE,
NASA

Mr. GERSTENMAIER. Thank you. Chairman Babin, Ranking Member Bera, and Members of the Committee, thank you for the opportunity to be here today to represent the NASA teams supporting the Commercial Crew Development Program.

Over the past several years, there's been tremendous amount of work completed. The hard work completed, the analysis, the design

work completed, as well as the testing is direct evidence of the tremendous amount of work that's been accomplished. I'm sure the other panelists will cover in detail the quality and quantity of the work completed. My written testimony additionally includes references to the work that's been completed.

The work completed took longer than originally planned, but many technical issues were discovered and resolved. This extra time that was taken in this development phase will help reduce the risk and magnitude of additional schedule delays.

This is a critical time in the program as manufacturing is in high gear, testing is being completed, and verification and validation requirements are being addressed by NASA. The program is approximately one year away from the first crew flights to ISS. This is an excellent time to reflect on the work completed and the work to go. This hearing is very timely.

The NASA team is fully aware of the amount of work to go and the requirements that need to be completed, reviewed, and closed by NASA and its partners. NASA has been fully engaged with the partners during their design and testing and manufacturing processes. NASA has directly witnessed tests. NASA has done our own assessments in selected areas, and we have requested extra tests from our partners and even done our own tests. This involvement and interaction helps as NASA reviews documents for closure.

NASA is aware of the schedule but not driven by the schedule. NASA worked last year to add additional Soyuz flights to protect if additional time was required for certification. Soyuz capability is available through the fall of 2019. The manufacturing time of a Soyuz of approximately three years will not allow additional Soyuz to be manufactured. We are brainstorming ideas to provide additional schedule time, if needed.

Additionally, as we do this, we are looking for ways to allow the partners to reach an operational tempo after certification.

The ISS program is looking at ways to maximize ISS operations while allowing for some delays and launch dates. Having selected two partners helps to relieve the schedule concerns if a major problem arises. NASA is doing everything possible to be prepared and allow time for a solid review of the design and the data.

NASA's aware that the schedule can be a negative influence to a good design and safe flight if it is the only consideration. As one way to protect against undue schedule pressure, NASA has implemented independent technical authorities. This allows for rigorous discussion on technical topics. This discussion could be seen as a negative but should rather be seen as a positive and a way to technically compare and contrast design options.

NASA is prepared to make timely decisions. Many of these decisions will be risk-versus-risk decisions. And NASA is prepared to make these based on the technical data available at the time of the decision.

Even after certification is complete, we must continually compare the actual performance of the systems to the design performance. We also must look at the environments in which the vehicle is flying to again make sure that the vehicles have the proper safety margins. We need to be prepared and allow the design to change, even after the official formal certification.

This is a critical time in the Commercial Crew Program. The decisions being made today will affect the safe and successful operation of the systems for years to come. NASA is fully ready for this phase and has the insight and ability to certify a safe and reliable system in a timely manner.

I look forward to your questions and a good, informative hearing. Thank you.

[The prepared statement of Mr. Gerstenmaier follows:]

HOLD FOR RELEASE
UNTIL PRESENTED
BY WITNESS
January 17, 2018

Statement of
William H. Gerstenmaier
Associate Administrator for Human Exploration and Operations
National Aeronautics and Space Administration

before the

Subcommittee on Space
Committee on Science, Space and Technology
U. S. House of Representatives

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to appear before you today to discuss the status of NASA's Commercial Crew Program (CCP). The CCP is working with the American aerospace industry to develop and operate a new generation of spacecraft and launch systems capable of carrying crews to space, including the International Space Station (ISS). Partnering with the commercial space industry for access to space and the ISS will bolster American leadership, reduce our current relianee on foreign providers for this service, and help stimulate the American aerospace industry. Additionally, by supporting new approaches for the development of human spaceflight capabilities, NASA is laying a foundation for a more affordable and sustainable future for human spaceflight.

Under this program, NASA is facilitating the development of two, independent U.S. human space transportation systems using an acquisition model featuring fixed-price contracts. Under this acquisition model, NASA seeks to define requirements up front and pay the contractor only when contract milestone are successfully completed. This approach is meant to shift some of the financial risk from taxpayers, ultimately decreasing the costs of developing the systems. Additionally, under this model, NASA ensures that companies retain commercial rights to intellectual property, which will allow these crew transportation systems to serve a much larger market than just NASA. Finally, NASA requires a high-level of safety, but tailors its human-rating requirements to enable new approaches in design while maintaining high levels of safety. NASA is deeply involved throughout the development and certification processes, and both NASA and industry have invested time, money, and resources in the development of these systems. There is a shared accountability between NASA and industry for the safety of the spacecraft.

Once operational, commercial transportation missions to and from the ISS will provide expanded astronaut flight opportunities, additional research time, and broader opportunities for discovery on the orbiting laboratory. NASA is using research on ISS to

develop strategies to overcome the challenges of long-duration spaceflight necessary for cis-lunar and deep space exploration. NASA also is enabling commercial companies to explore and develop new revenue-generating opportunities utilizing the ISS and commercial cargo and crew capabilities, with the goal of private companies expanding the economic sphere of the United States in low-Earth orbit.

NASA and our private sector CCP partners, SpaceX and Boeing, are successfully meeting the required milestones to finish development of their respective systems. The schedule for this activity has taken longer than originally envisioned. The next year will be particularly challenging for our team as some of the most difficult milestones are just ahead. Within the next 12-20 months, we expect to achieve these milestones and then re-establish U.S. human access to space through the Commercial Crew Program. Once complete, these efforts will have resulted in a significant advancement for human spaceflight - the development of two, independent U.S. human spaceflight systems, with NASA's investment in the development of the partners' crew transportation systems being less than $5 billion.

Recent Progress

NASA and our commercial partners, Boeing and SpaceX, made significant strides in 2017 towards returning human space launch to the United States. Each company continued to develop and test their space systems to fly astronauts for the Agency to and from the ISS.

2017 began with the award of four additional crew rotation missions to Boeing and SpaceX. The four additional missions brought the total number of crew rotation missions awarded to each provider to six and will provide crew transportation capability to the ISS through 2024, possibly beyond. The missions will fly under FAA licenses following NASA certification of the crew transportation systems.

The four NASA astronauts who are training to fly the test flights on Boeing's Starliner and SpaceX's Crew Dragon spent time evaluating both providers' progress during 2017 along with many NASA engineers. The astronauts are learning about the systems, being fitted for spacesuits, and readying for flight tests to and from the ISS.

The ISS Program continued preparations for the new commercial spacecraft to arrive. During Orbital ATK's resupply mission to the Station in November 2017, the cargo spacecraft maneuvered above the Harmony module prior to its release. There, it gathered data relevant to future rendezvous and docking operations for U.S. commercial crew vehicles that will be arriving for a linkup to Harmony's international docking adapters. Other work included the ISS crew installing and performing check-outs of a control panel on Harmony for the docking adapter.

Boeing's Starliner continued to be manufactured inside of the Commercial Crew and Cargo Processing Facility at NASA's Kennedy Space Center in Florida. Three Starliners

are in production inside the manufacturing facility. Last year, the Starliner was powered on for the first time, and test versions of the spacecraft have been shipped to various test facilities across the United States to be put through the extremes necessary to understand how the Starliner will perform in the space environment.

The Starliner will be launched by an Atlas V rocket from Space Launch Complex 41 on Cape Canaveral Air Force Station in Florida. Last year, an emergency exit system was installed and tested on the launch pad. The system will be available to astronauts and launch support personnel in the unlikely event of an emergency prior to liftoff.

SpaceX is manufacturing the Crew Dragon spacecraft inside the company's headquarters and manufacturing facility in Hawthorne, California. In total, SpaceX has six Crew Dragon modules in various stages of production and testing, including a qualification module, a life support system testing module, the two spacecraft for flight tests, and the first two for fully operational missions.

Last year, SpaceX hosted its inaugural flight from historic Launch Complex 39A at NASA's Kennedy Space Center in Florida, which will be used for its crew launches. In addition to performing water deluge sound suppression tests, multiple human-in-the-loop and software simulations, and completing structural upgrades at the site, the company successfully launched 12 missions from 39A in 2017, providing experience with and insight into a pad that will be used for commercial crew missions. The company's crew access arm will be installed on the launch pad this year and provide a bridge between the crew access tower and SpaceX's Crew Dragon spacecraft for astronauts flying to the space station. The Crew Dragon will be launched from Complex 39A on the company's Falcon 9 rocket.

NASA has been intimately involved in all these activities. The commercial crew contracts have broad insight and oversight clauses enabling NASA to have a thorough understanding of the companies' designs and testing. The contracts also require submission of specified data deliverables, reports, review packages, and plans throughout the performance of the contracts to enable NASA to continuously monitor and assess the companies' performance.

Requirements

NASA requirements for commercial crew space transportation include delivering four astronaut crewmembers and equipment safely to the space station and returning them to Earth. The providers also must assure crew safety in the event of an emergency on the launch pad, as well as during launch, ascent to orbit, and return to Earth. The spacecraft must demonstrate it can serve as a 24-hour safe haven during an emergency in space and be able to stay docked to the station for at least 210 days.

In addition to all the technical analytical work and ground testing that is being completed to ensure that the systems meet NASA's safety and performance requirements, each

company proposed two orbital test flights prior to certification. The first orbital tests, known as Orbital Flight Test for Boeing and Demonstration Mission 1 for SpaceX, will be uncrewed demonstration missions to the ISS. After the uncrewed test flights, each company will carry out a test flight to the ISS with crew, known as Crewed Flight Test for Boeing and Demonstration Mission 2 for SpaceX. These test flights will show that the fully integrated rocket and spacecraft system can launch, maneuver in orbit, and dock to the ISS, as well as to validate that all its systems perform as expected. These will be challenging missions and will require NASA and the companies to work together to be successful.

In addition to these integrated tests, both companies have abort tests planned. SpaceX successfully completed a launch pad abort test in May 2015 and Boeing is scheduled to complete its launch pad abort test in April 2018. SpaceX also has an in-flight abort test planned in October 2018. These tests are all part of the validation and demonstration of the integrated operation of the system and its abort capability.

In all, NASA has 280 individual requirements that the companies must meet in order to achieve certification. One requirement is the loss of crew number, which is a summary of a probabilistic risk assessment of all vehicle systems. The methodology used to calculate loss of crew is used by engineers to analytically compare the effects of specific technical options on the overall vehicle and mission design. For commercial crew, the loss of crew requirement is 1 in 270 for a 210 day ISS mission (The overall requirement is 1 in 270. Of that number, 1 in 200 is allocated to the partners' systems and the remaining is allocated to operational mitigations such as inspection and repair.), which essentially means that statistically there is a high likelihood that we would lose a crew in 270 missions. This requirement is a very stringent one. At the end of the Space Shuttle's operational life, its loss of crew number was 1 in 90. Our partners and NASA have expended considerable time and energy in satisfying this requirement, and their designs are undoubtedly better and safer for this effort.

The loss of crew statistical assessment is just one tool in which NASA evaluates the safety or certification of a system. It is conceivable that NASA's initial specific loss of crew number may not be met for either partner. NASA will continue to make every reasonable effort to reduce risk. The Aerospace Safety Advisory Panel highlighted during their second quarterly meeting of 2017 the importance of viewing vehicle safety comprehensively and cautioned against relying too narrowly on specific loss of crew models. It said, "One must be wary of being too pernicious in the application of a specific [loss of crew] number and must look at whether the providers have expended the necessary efforts and engineering activity to make the systems as safe as they can and still perform the mission. Currently, review of both providers appears to be positive. There was no indicated area where by spending additional dollars the providers could have made their systems considerably safer." The loss of crew metric is a useful tool when developing human space transportation systems, but it is not a panacea to address the risk and it is by no means absolute.

We can never address every possible condition that may be experienced as part of space launch and orbital flight, because our knowledge of hardware and software behavior, as well as the stressing environments in which they operate, is always imperfect. Impacts from small space debris is a large contributor to the risk model. We use best engineering practice, within the bounds of reasonableness, to test and analyze what we expect to be nominal and bounding operational cases. Then we implement appropriate hazard controls to mitigate known failure consequences. Still, there are always unknowns and we will continue to look for these unknowns, and search for ways to discover and mitigate them.

Notably, risk is never mitigated to zero. For all crewed and uncrewed missions, including Commercial Crew, there is residual risk that NASA agrees to accept, because additional actions to further mitigate risk are not pragmatic, either due to knowledge limitations or diminishing returns to applying resources that can never be unlimited. No human spaceflight mission can be made absolutely safe by any reasonable definition of that word, due to the unknowns, the incredible expenditure of energy required to achieve orbital velocity, and the unforgiving nature of the space environment.

We also need to be careful and not assume all work stops once a design is certified and flown. On each flight, we need to look carefully at the data and detect minor flaws before they become major failures. We also need to continually look for new ways to monitor the environment in which these systems are flying. As these system take to flight next year we need to work with our partners and look for ways to improve safety. Human spaceflight demands this rigor and need to stay 'hungry'.

Technical Challenges

Space transportation system design, manufacturing, and testing is difficult and often requires complex trade-offs to develop and operate the optimal system to fly humans. An example of these trade-offs is the challenge of balancing the desire to build a robust spacecraft that can protect the crew from orbital debris with the inherent risk of needing more powerful propulsion to fly the additional mass needed for such protection. Also, spacecraft and launch systems generally need to be as compact as possible while still meeting NASA's requirements for redundancy and failure tolerance. Balancing requirements for nominal mission operation and failure scenarios also is challenging. An example of this is the need to have suits that protect crew members during cabin depressurization scenarios yet are flexible enough to allow the crew to perform critical manual operations. These are tough systems engineering problems that our industry partners are addressing.

Both partners are working through challenges in their designs. Boeing and ULA resolved aerodynamic issues that imparted unacceptable loads on the upper stage of the launch vehicle. This required extensive wind tunnel testing, additional design and analysis, aerodynamic database development, and new hardware. The work resulted in design changes to the spacecraft adding an "aero skirt" configuration that smoothed the air flow

across the spacecraft and upper stage of the launch system during endo-atmospheric flight. In September of 2016, SpaceX experienced a major anomaly during propellant loading in preparation for an on-pad "hot fire" engine test that resulted in the loss of the launch vehicle and commercial satellite. That anomaly was attributed to a failure of one of their helium composite overwrap pressure vessels (COPV). Since the CCtCap award, NASA had been working with SpaceX on their crewed version of the helium COPV with the required factor of safety. Since the anomaly, NASA has been working with SpaceX to first understand the failure and then understand what the failure has taught them and us about the safe design and operation of these tanks for crewed missions.

There are several more technical challenges that our partners and NASA will have to work through in the months ahead, including software development issues, parachute testing, and detailed abort scenarios. Both partners have work to complete on their spacesuits and launch pads, and the test flights will be difficult to successfully accomplish. I am confident in our partners' ability to meet these challenges with NASA's assistance. NASA also will have a lot of verification products to review. NASA is prepared. However, these challenges may impact the schedule for milestone completion.

Schedule

As mentioned, both CCP partners have made considerable progress toward providing human space transportation to low-Earth orbit and the ISS. As of January 2018, the following table shows the planning dates for the major development milestones.

Milestone	Planned Date (as of January 2018)
SpaceX Demonstration 1 (no crew)	August 2018
SpaceX In-Flight Abort Test	October 2018
SpaceX Demonstration 2 (crewed)	December 2018
SpaceX Certification	February 2019
Boeing Pad Abort Test	April 2018
Boeing Orbital Flight Test (no crew)	August 2018
Boeing Crewed Flight Test (crewed)	October 2018
Boeing Certification	January 2019

Our partners have experienced some delays that are typical in a complex spaceflight development effort. The CCP is a large, complex development effort whereby the partners are expected to conform to a set of requirements in a fixed price contract. Given the technical challenges associated with the designs of both partners' crew transportation systems, as well as the large amount of work required of NASA to verify and validate that all requirements have been met, additional delays from the dates shown above may be experienced.

NASA is tracking this situation carefully. NASA receives an updated integrated master schedule from each company on a monthly basis. Additionally, we require the

companies to formally report on the status of their schedules on a quarterly basis. Finally, NASA independently calculates a Schedule Risk Analysis as part of the program's reporting to NASA Headquarters.

I caution not to focus solely on schedule as a metric for the CCP. While we need to be schedule aware, we do not want to place undue pressure on our partners to meet schedule. The human space transportation capabilities that result from the CCP will be used for generations. The CCP systems need the time to be able to go through the rigor of a formal certification effort successfully. Also, strictly adhering to a timeline can lead to either accepting an inappropriate design or disapproving a design feature that could result in more efficient, safer, or less costly operation in the future.

While the systems are not yet complete and further delays could be experienced, the current dates above reflect a development effort of approximately seven years for two, independent U.S. human spaceflight systems, which is very efficient in the history of the nation's human spaceflight experience.

Contract and Budget Baseline

The original potential maximum contract values of the Commercial Crew transportation Capability (CCtCap) contracts were $4.229 billion for Boeing and $2.599 billion for SpaceX. Since the beginning of the contracts, NASA has added some additional technical scope to the contracts, which increased their value. As of December 2017, the current potential maximum contract value for Boeing is $4.322 billion for Boeing (a 2.2% increase) and $2.646 billion for SpaceX (a 1.8% increase). The additional scope was added to further enhance crew safety, primarily crew exposure to Translational Acceleration limits. Changing this requirement impacted the crew seat position in the capsules and drove additional milestones for both providers. NASA also updated requirements related to ISS interfaces and software and accommodated changes from the NASA Docking System. In addition, NASA added some cargo on test flights to the ISS.

It is a testament to the NASA team, for the initial high-quality work in establishing the baseline CCP requirements and then in maintaining a stable requirements environment, that these modest increases have been experienced. It should also be noted that these increases were entirely absorbed within the CCP budget – there has been no increase to NASA's budget request for the CCP.

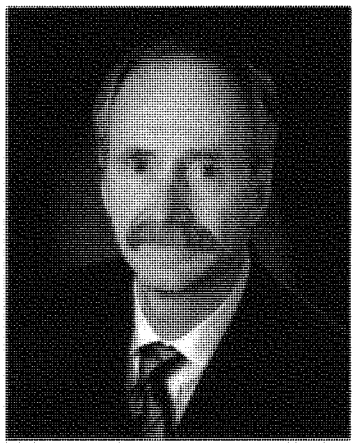
There may be future requirements changes that will be required prior to certification. As I stated, the most challenging year is ahead. However, if no major issues are encountered, NASA's investment in the development of the SpaceX and Boeing crew transportation systems will be less than $5 billion.

Conclusion

NASA is looking to the U.S. private sector to develop and operate safe, reliable, and affordable crew transportation to space. Working with the commercial space industry for access to LEO will bolster American leadership, reduce our current reliance on foreign providers for this service, and help stimulate the American aerospace industry. By supporting the development of human spaceflight capabilities, NASA is also working to lay the foundation for more affordable and sustainable future human space transportation capabilities, which is likely to open up new opportunities for commercial, scientific, and governmental activities in space. Nonetheless, human spaceflight is a very difficult endeavor. Continued support for Commercial Crew is critical for NASA to develop a safe, competitive, domestic program that will enable us to end the Nation's reliance upon foreign governments for crew transportation and increase innovation in the space transportation sector. The CCP, along with NASA's other human spaceflight programs enable us to keep discovering, researching, and innovating, and are all critical components needed to expand human presence into the solar system. NASA's human spaceflight team is ready for these challenges. Congressional support is critical and appreciated.

Mr. Chairman, I would be happy to respond to any questions you or the other Members of the Committee may have.

WILLIAM H. GERSTENMAIER
ASSOCIATE ADMINISTRATOR FOR
HUMAN EXPLORATION AND OPERATIONS



William H. Gerstenmaier is the associate administrator for the Human Exploration and Operations Mission Directorate at NASA Headquarters in Washington, DC. In this position, Mr. Gerstenmaier provides strategic direction for all aspects of NASA's human exploration of space and cross-agency space support functions of space communications and space launch vehicles. He provides programmatic direction for the continued operation and utilization of the International Space Station, development of the Space Launch System and Orion spacecraft, and is providing strategic guidance and direction for the commercial crew and cargo programs that will provide logistics and crew transportation for the International Space Station.

Mr. Gerstenmaier began his NASA career in 1977 at the then Lewis Research Center in Cleveland, Ohio, performing aeronautical research. He was involved with the wind tunnel tests that were used to develop the calibration curves for the air data probes used during entry on the Space Shuttle.

Beginning in 1988, Mr. Gerstenmaier headed the Orbital Maneuvering Vehicle (OMV) Operations Office, Systems Division at the Johnson Space Center. He was responsible for all aspects of OMV operations at Johnson, including development of a ground control center and training facility for OMV, operations support to vehicle development, and personnel and procedures development to support OMV operations. Subsequently he headed the Space Shuttle/Space Station Freedom Assembly Operations Office, Operations Division. He was responsible for resolving technical assembly issues and developing assembly strategies.

Mr. Gerstenmaier also served as Shuttle/Mir Program operations manager. In this role, he was the primary interface to the Russian Space Agency for operational issues, negotiating all protocols used in support of operations during the Shuttle/Mir missions. In addition, he supported NASA 2 operations in Russia, from January through September 1996 including responsibility for daily activities, as well as the health and safety of the NASA crewmember on space station Mir. He scheduled science activities, public affairs activities, monitored Mir systems, and communicated with the NASA astronaut on Mir.

In 1998, Mr. Gerstenmaier was named manager, Space Shuttle Program Integration, responsible for the overall management, integration, and operations of the Space Shuttle Program. This included development and operations of all Space Shuttle elements, including the orbiter, external tank, solid rocket boosters, and Space Shuttle main engines, as well as the facilities required to support ground processing and flight operations.

In December 2000, Mr. Gerstenmaier was named deputy manager, International Space Station Program and two years later became manager. He was responsible for the day-to-day management, development, integration, and operation of the International Space Station. This included the design, manufacture, testing, and delivery of complex space flight hardware and software, and for its integration with the elements from the International Partners into a fully functional and operating International Space Station.

Named associate administrator for the Space Operations Mission Directorate in 2005, Mr. Gerstenmaier directed the safe completion of the last 21 Space Shuttle missions that witnessed assembly complete of the International Space Station. During this time, he provided programmatic direction for the integration and operation of the International Space Station, space communications, and space launch vehicles.

In 2011, Mr. Gerstenmaier was named to his current position as associate administrator for the Human Exploration and Operations Mission Directorate.

Mr. Gerstenmaier received a bachelor of science in aeronautical engineering from Purdue University in 1977 and a master of science degree in mechanical engineering from the University of Toledo in 1981. In 1992 and 1993, he completed course work for a doctorate in dynamics and control with emphasis in propulsion at Purdue University.

Mr. Gerstenmaier is the recipient of numerous awards, including three NASA Certificates of Commendation, two NASA Exceptional Service Medals, a Senior NASA Outstanding Leadership Medal, the Meritorious Executive Presidential Rank Award, and Distinguished Executive Presidential Rank Award. He also was honored with an Outstanding Aerospace Engineer Award from Purdue University. Additionally, he was twice honored by Aviation Week and Space Technology for outstanding achievement in the field of space. His other awards include: the AIAA International Cooperation Award; the National Space Club Astronautics Engineer Award; National Space Club Von Braun Award; the Federation of Galaxy Explorers Space Leadership Award; AIAA International Award; the AIAA Fellow; Purdue University Distinguished Alumni Award; and honored at Purdue as an Old Master in the Old Masters Program; recipient of the Rotary National Award for Space Achievement's National Space Trophy; Space Transportation Leadership Award; the AIAA von Braun Award for Excellence in Space Program Management; and the AIAA von Karman Lectureship in Astronautics.

He is married to the former Marsha Ann Johnson. They have two children.

October 2015

Chairman BABIN. Thank you, Mr. Gerstenmaier. Now I'd like to recognize Mr. Mulholland for five minutes to present his testimony.

TESTIMONY OF MR. JOHN MULHOLLAND,
VICE PRESIDENT AND PROGRAM MANAGER
FOR COMMERCIAL PROGRAMS,
BOEING SPACE EXPLORATION

Mr. MULHOLLAND. Chairman Smith, Chairman Babin, Ranking Member Johnson, Ranking Member Bera, and Members of the Committee, on behalf of The Boeing Company, thank you for the opportunity to provide an update on the Commercial Crew Program.

We are proud to have been a trusted partner with NASA on every domestic human spaceflight program. We have a unique and singular understanding of the strategic importance of having an American-made crew transportation system for safe, reliable, and affordable access to low-Earth orbit. I will emphasize safe again as for that is our ultimate judgment on our mission. That said, we understand that having this capability as soon as possible is critically important for the International Space Station to continue its important mission as a world-class national lab.

We have the full support of The Boeing Company, and a strong, value-added relationship with our NASA partner. We've made tremendous progress and have overcome several issues that are typical of complex development programs since we last testified in 2015.

Our launch vehicle, the Atlas V, has flown 74 missions with 100 percent mission success providing unparalleled safety, mission assurance, and schedule reliability. The launch site crew access tower has been erected, and other site modifications are progressing well ahead of need.

The structural test article entered test in December 2016 and is undergoing a complex series of static loads, modal analysis, ordinance operation, and separation system verification. The test series is greater than 50 percent complete.

The service module hot fire test article has been delivered to the test site and is near completion of cold-flow testing. Following this phase, the system will be loaded with propellant, and all propulsion system functions will be tested.

Spacecraft 1 has finished initial power-on testing, ground verification testing, and is undergoing final outfitting prior to mate of the crew module and the service module. This test article will be sent to the test site for the pad abort test in Q2 2018.

Spacecraft 2 initial power-on testing will occur in early February, followed by final outfitting and mate prior to being shipped to the test site for environmental qualification testing early this summer before returning to Florida for retrofitting to support the crew flight test in Q4 2018.

Spacecraft 3 lower dome secondary structure is in build to support initial power-on testing in April. This spacecraft will be used for the uncrewed test flight in Q3 2018.

The land landing qualification testing has successfully completed, proving our system can safely land on land under both nominal and failure cases.

Flight software released its latest drop in December and currently stands at over 98 percent of full functionality.

Over 25 percent of the verifications to be approved by NASA have been completed and delivered, and over 11,000 hazard control verifications have been closed out and delivered.

Training is under way with NASA's commercial crew cadre and our mission operations team thanks to new, state-of-the-art Starliner training systems at the Johnson Space Center.

As you can see, the team has successfully transitioned from design into integrated build and test. The last time I was here, there were some concerns over whether or not NASA and its partners were providing the Aerospace Advisory Panel with enough insight into our systems and processes. I promised this Committee, and then-chair Admiral Dyer, that Boeing would continue to provide the ASAP the appropriate level of access into the development of the Starliner. In fact, we offer all of NASA's advisory committees and reporting agencies, including the Government Accountability Office, full insight into our progress, challenges, and schedule. We believe transparency is essential in this business, and I personally feel that the reviews, findings, and feedback add value to our systems and processes.

We are well aligned with our customer on crew safety and mission assurance, and our analyses show that we exceed our requirements for crew safety. While we're focused on meeting our 2018 forecast dates, we're equally committed to performing those safely. We bring the same quality to commercial spaceflight that we bring to our servicemen and women, astronauts on board the station, and to the traveling public every day.

Thank you again for the opportunity to be here today, and I look forward to answering your questions.

[The prepared statement of Mr. Mulholland follows:]

Testimony of John Mulholland
Vice President and Program Manager
Boeing's Commercial Crew Program
January 17, 2018

Chairman Babin, Ranking Member Bera, and members of the Committee, on behalf of The Boeing Company, thank you for the opportunity to provide an update on the Commercial Crew Program.

We have been a partner with NASA on every domestic human spaceflight program, Mercury, Gemini, Apollo, Apollo-Soyuz, Space Shuttle, International Space Station, and now Commercial Crew and the Space Launch System. We have a unique and singular understanding of the strategic importance of having an American-made crew transportation system for safe, reliable and affordable access to low-Earth orbit. I will emphasize safe again, as for us that is the ultimate judgment on our mission. That said, we understand that having this capability as soon as possible is critically important for the International Space Station to continue its important mission as a world-class national lab.

The first flight of the CST-100 Starliner will represent a major milestone for the future of human spaceflight. To make that successful, we have the full support of The Boeing Company, and a strong, value-added relationship with our NASA partner.

Background

Boeing's vision is to connect, protect, explore and inspire. Those concepts span everything we do as a company – commercial, defense, and services. Human spaceflight fits squarely within that vision and is a market Boeing is firmly committed to. When we entered our 100th year of operation, Boeing reaffirmed the importance of space in our own strategy by naming human space exploration as one of our six key focus areas for our Defense, Space & Security business unit.

We are proud to be NASA's trusted partner as we continue to innovate critical new systems for human spaceflight activities in low-Earth orbit and beyond. But as I mentioned earlier, Boeing's success depends entirely upon the quality and safety of our products. As NASA continues to advance scientific research aboard the International Space Station (ISS) and extend exploration deeper into our solar system with the Space Launch System (SLS) and Orion, the Commercial Crew Program is pivotal to achieving NASA's human exploration vision within the economic constraints of a larger national agenda.

The Commercial Crew Program's immediate purpose is to provide safe, reliable and affordable access to low-Earth orbit, including the International Space Station, ending America's reliance on Russian transportation for U.S. crews.

Since the inception of the NASA Commercial Crew Development effort, CCDev, in 2009, Boeing has utilized a robust program management approach, proven spaceflight systems and hardware, and a rigorous systems engineering development and certification approach to provide NASA and U.S. taxpayers with the most reliable solution to meet national needs.

This rigorous engineering process led to the successful completion of all development phases of NASA's Commercial Crew Program. We are proud to be the only Commercial Crew supplier to close NASA's previous development phase, the Commercial Crew Integrated Capability (CCiCap), on-time. CCiCap, as well as the Certification Products Contract phase of the program, laid the groundwork for our design completion and path toward certification during this Commercial Crew Transportation Capability (CCtCap) contract, which was awarded in September 2014.

In response to the request of the Committee, my testimony addresses a review of our capabilities, progress, key milestones and challenges ahead, and the risks we are mitigating while preparing to fly, and ultimately receive NASA certification.

1. Review of Commercial Crew Transportation System capabilities, architecture and systems

Our Commercial Crew Transportation System, called the CST-100 Starliner, is a "full service" system. It provides all elements needed to transport crew and cargo to and from orbit, including crew training and mission planning, cargo integration, spacecraft assembly, integration and testing, launch vehicle integration and testing, launch and mission operations, and crew and cargo recovery.

Boeing's robust design uses proven technologies to reduce system complexity, which results in improved reliability and safety. It reduces development risk, improving predictability of cost and schedule. It also lowers overall cost. Our design also will support transportation services to emerging low-Earth orbit platforms, such as commercial space stations.

In our concept of operations, Starliner launches from Florida's Space Coast on a United Launch Alliance (ULA) Atlas V rocket, the most reliable rocket ever flown with a 100% success rate on 74 missions and counting.

The fully autonomous Starliner is baselined for five passengers plus cargo on missions to the International Space Station, but it also has the versatility to accommodate up to seven passengers and cargo. After an eight-hour flight, the Starliner will rendezvous with a low-Earth orbit platform, such as the International Space Station. The capsule stays attached to the orbiting

platform for at least six months to serve as the crew's on-orbit "lifeboat." When it is time to return crew members to Earth, the capsule detaches from the platform, jettisons its service module and re-enters the atmosphere behind the protection of an ablative heat shield. Boeing's Starliner is currently the only capsule being certified by NASA to land on land, which allows quick access to crew members and valuable scientific payloads. It uses a parachute and airbag landing system for a comfortable deceleration and safe impact.

A land landing also increases reusability when compared with a water landing. The Starliner capsule can be refurbished and is reusable for up to 10 missions. The system does support water landings after pad or ascent aborts, targeted contingency landings, and emergency landings – providing additional measures of risk mitigation.

We have designed our capsule to be compatible with a variety of launch vehicles, but chose the Atlas V for the first test flights and service missions. Once additional launch vehicles have demonstrated sufficient technical and schedule reliability necessary for crew flights, we maintain the ability to on-ramp them in our ongoing effort to drive life-cycle affordability. To date, none have satisfied those requirements beyond the Atlas V.

2. Update of progress made and milestones ahead

Our approved certification plan follows a process very similar to the process that we followed for the space shuttle and space station, and is consistent with Boeing commercial programs, such as commercial airplanes and satellites. From a payable milestone perspective, we have completed 27 of 43 development milestones and 8 of 24 certification milestones under the CCtCap contract. We've made tremendous progress, and have overcome several issues that are typical of complex development programs since we last testified in 2015.

- Our launch vehicle, the Atlas V, has flown 74 missions with 100% mission success, providing unparalleled safety, mission assurance and schedule reliability.
- The Crew Access Tower at Space Launch Complex 41 has been erected and other site modifications are progressing well ahead of need.
- The launch vehicle that will power our first uncrewed flight is in final production at the United Launch Alliance factory in Decatur, Ala., and the major components for the crew test flight are moving through the factory.
- All of our test and flight spacecraft are fielded or are in build.
- The Structural Test Article consists of a crew module, service module and launch vehicle adapter. The test article entered test in December 2016 and is undergoing a complex test series of static loads, modal analysis, ordinance operation and separation system verification. The test series is greater than 50% complete.
- The Service Module Hot Fire test article has been delivered to the test site and is near completion of the first test phase, cold-flow testing. Following cold-flow test

completion, the system will be loaded with propellant, and all propulsion system functions, including abort, on-orbit maneuvers, and the de-orbit burn series will be tested.

- Spacecraft 1 has finished initial power-on testing, ground verification testing, and is undergoing final outfitting prior to mate of the crew module and service module. This test article will be sent to the test site for the Pad Abort Test in Q2 2018.
- Spacecraft 2 initial power-on testing will occur in early February, followed by final outfitting and mate prior to being shipped to the test site for environmental qualification testing early this summer. The spacecraft will undergo thermal vacuum, acoustic vibration, and emission testing before returning to Florida for retrofitting to support the Crew Flight Test in Q4 2018.
- Spacecraft 3 lower dome secondary structure is in build to support initial power-on testing in April. This spacecraft will be used for the uncrewed flight test in Q3 2018.
- Work across all systems and components is progressing to near-term completions.
- The land landing qualification testing has successfully completed, proving our system can safely land on land under both nominal and failure cases.
- Three full-scale parachute drop tests remain, including one later this month.
- Over 75% of our component qualification testing has been successfully completed.
- Flight software released its latest drop in December and currently stands at over 98% of full functionality.
- All design drawings have been released.
- Over 25% of the verifications to be approved by NASA have been completed and delivered, and over 11,000 hazard control verifications have been closed out and delivered.
- Training is under way with NASA's Commercial Crew Cadre and our Mission Operations team thanks to new, state-of-the-art Starliner training systems at the Johnson Space Center.
- Our Flight Control Team products are at greater than 80% maturity, and multiple integrated simulations have already been completed.

As you can see, the team has successfully transitioned from design into integrated build and test. While we're focused on meeting our 2018 forecast dates, we are fully committed to performing those safely. We bring the same quality to commercial spaceflight that we bring to our service men and women, astronauts on-board the station, and to the traveling public, every day.

3. Development program challenges and risk mitigation

As with any complex development program, we have faced and overcome a number of challenges – both technical and programmatic. Several of these issues affected our original schedule. I am proud of the response by our team, addressing these challenges head-on to ensure the robustness and mission assurance of our system.

A key strength that Boeing provides to NASA is that we have a host of resources in a wide range of engineering and manufacturing disciplines, and we have applied this expertise early to drive resolution of emerging risks. This deep talent pool and ability to share lessons learned across a wide range of aerospace development and production programs has been instrumental in addressing and resolving risk to NASA's benefit.

Closing

The last time I testified before this Committee in 2015, there were concerns over whether or not NASA and its partners were providing the Aerospace Safety Advisory Panel (ASAP) with enough insight into our systems and processes. I promised this committee, and then-chair Vice Admiral Dyer, that Boeing would provide the ASAP the appropriate level of access into the development of the Starliner.

In fact, we offer all of NASA's advisory committees and reporting agencies – including the Government Accountability Office – full insight into our progress, challenges and schedule. We believe transparency is essential in this business, and I personally feel that the reviews, findings and feedback add value to our systems and processes.

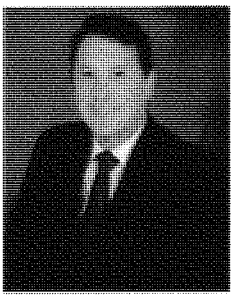
We are well aligned with our customer on crew safety and mission assurance, and our analyses show that we exceed our requirements for crew safety. We also are making steady progress on achieving certification. In fact, we recently met with NASA to conduct a thorough review of our design, performance, verification, validation, test activities and station integration plans to ensure flight tests can continue in confidence. That milestone – called the ISS Design Certification Review – went well and will close following the completion of the contractually required service module hot-fire test mentioned above.

We would like to thank everyone who has contributed to this program. Colleagues at Boeing and NASA, the thousands of supplier employees across 38 states – your hard work, dedication and passion is unparalleled. To the members of this Committee and staff, thank you again for your continued support and the opportunity to be here today.

BOEING

Biography

Defense, Space & Security
929 Long Bridge Drive
Arlington, VA 22202-4208
www.boeing.com



JOHN P. MULHOLLAND

Vice President and Program Manager
Commercial Crew Program
BDS Development

As vice president and program manager of Boeing's Commercial Crew Program, John Mulholland leads the development of the Crew Space Transportation (CST)-100 Starliner system. Mulholland ensures that proven innovations and capabilities from across Boeing are used in the design, development and operations of Starliner vehicles to support NASA and other commercial customers.

Prior to his present position, Mulholland was the vice president and program manager for the Boeing Space Shuttle Program, responsible for overall direction and successful execution, from January 2008 to August 2011. Mulholland led Boeing in its role as the major subcontractor to United Space Alliance in support of its operations contract with NASA's Space Shuttle Program.

Mulholland also was the program director and chief engineer for the Boeing Space Shuttle Orbiter team. In that role, he was responsible for resolving pre- and in-flight space shuttle engineering technical issues and maintaining the fleet's mission readiness.

Previously, he was a Boeing associate program director for Orbiter Vehicle Engineering during which he led a team of about 400 employees in Houston, Huntington

Beach, California, and Kennedy Space Center, Florida. In that role, he was responsible for space shuttle sustaining engineering, anomaly resolution and certification of flight readiness.

From 1996 to 2002, he was the space shuttle deputy manager of operations and project engineer at NASA's Johnson Space Center, where he was responsible for orbiter vehicle modifications, flight and ground processing anomaly resolution, and flight preparation and vehicle modification processes.

A NASA Exceptional Achievement Medal recipient, Mulholland was employed at NASA's White Sands Test Facility in New Mexico from 1986 to 1996 and was responsible for shuttle propulsion testing, including refurbishment of the orbiters' flight components.

Mulholland is a graduate of New Mexico State University with a Bachelor of Science in chemical engineering and a master's degree in mechanical engineering.

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Contact:

Rebecca Regan
CST-100 Starliner
Mobile: +1 321-607-2297
rebecca.a.regan@boeing.com

June 2017

Chairman BABIN. Thank you, Mr. Mulholland. I'd like to now recognize Dr. Koenigsmann for five minutes to present his testimony.

TESTIMONY OF DR. HANS KOENIGSMANN,
VICE PRESIDENT OF BUILD
AND FLIGHT RELIABILITY, SPACEX

Dr. KOENIGSMANN. Thank you. Mr. Chairman, Ranking Member Bera, Ranking Member Johnson, and Members of Committee, thank you for the opportunity to participate in today's important hearing.

SpaceX is proud to partner with NASA to develop the next generation of safe, reliable, and affordable space transportation for America's astronauts. On behalf of my more than 6,000 colleagues at SpaceX, I am pleased to be here to provide an update on our progress towards the first flight with crew later this year.

Mr. Chairman, SpaceX is designing, building, testing, and will soon operate the safest crew transportation system in history. We are working in close partnership with NASA, and we are deeply grateful for the ongoing guidance and confidence.

The Commercial Crew Program stands as a true example of the innovative safety improvements and cost savings that can be achieved under an effective public/private partnership.

In addition to designing and building the hardware, we will conduct all mission operations from crew training, launch and on-orbit activities to post-flight recovery. NASA sets high-level requirements and certifies us to fly. The SpaceX transportation system leverages our proven Falcon 9 launch vehicle and our Crew Dragon spacecraft.

Falcon 9 has successfully launched 46 times since 2010 including 18 flights in 2017, a new record. The vehicle has been designed from day one with robust margins, engine-out capability, and advanced safety systems to support astronaut flights. Falcon 9 is also the only operational orbital launch system with reusability capabilities which improves reliability and lowers cost.

The Crew Dragon spacecraft builds upon our successful flight heritage with our current cargo-configured Dragon spacecraft. We developed Dragon under the COTS Space Act Agreement with NASA. Since 2010, Dragon has successfully flown to orbit and back 14 times between sending cargo to the space station and back to Earth, a capability unique to Dragon. Crew Dragon takes this proven design and incorporates upgrades to ensure a safe and comfortable ride for astronauts.

The biggest safety innovation on Crew Dragon is our launch escape system. Fully integrated into the spacecraft, the system will safely propel Crew Dragon and the astronauts inside away from the launch vehicle in the event of an emergency. Unlike past generation systems that could only be used for the first few minutes of flight, our SuperDraco system gives the escape capability all the way to orbit. This is a major advancement for astronaut safety.

I'd like to give you an overview of some of the major achievements we've made in the program to date. In May of 2015 we conducted a successful pad abort test. Here, we simulated an emergency on the launch pad. Within a fraction of a second, the space-

craft escape system propelled it away from the pad, validating true escape capability in the event of a pad emergency.

In November of 2016, we completed functional testing of our life support system. We also completed a key space suit qualification milestone which including the lead engineer wearing the space suit he designed in a vacuum chamber to prove its capability.

In September 2017, we successfully made Dragon's pressure and service section of our first flight vehicle. This was a major milestone and a big step towards flight later this year. And in December, we completed the first round of qualification testing for our parachute system.

We have completed nearly all technical development required for Crew Dragon. At this point, we have multiple Crew Dragon spacecraft in testing or built right now.

Over the course of this year, we will complete final integration and validation ahead of our first astronaut flights. In August we plan to conduct an uncrewed test flight of the full system to and from the space station to validate that the system is safe for crew. Then we will launch our test flight with two NASA astronauts for a week mission to and from the space station in December. Following that, we will begin operational flights with a four-astronaut NASA crew complement.

Safely and reliably flying commercial crew missions remains the highest priority for SpaceX, and we will launch NASA astronauts only when both we and NASA are ready.

Mr. Chairman, I appreciate the opportunity to testify before you today, and I look forward to answering your questions.

[The prepared statement of Dr. Koenigsmann follows:]

STATEMENT OF
DR. HANS KOENIGSMANN
VICE PRESIDENT, BUILD AND FLIGHT RELIABILITY
SPACE EXPLORATION TECHNOLOGIES CORP. (SPACEX)

BEFORE THE
COMMITTEE ON SCIENCE, SPACE, & TECHNOLOGY
SUBCOMMITTEE ON SPACE
UNITED STATES HOUSE OF REPRESENTATIVES

JANUARY 17, 2018

Mr. Chairman, Ranking Member Bera, and Members of the Committee,

Thank you for the opportunity to participate in today's hearing on "An Update on NASA Commercial Crew Systems Development." SpaceX is proud to partner with NASA to develop the next generation of safe, reliable, and affordable transportation to space for America's astronauts, and we are working diligently toward flying astronauts this year. We appreciate the Committee's support of this important program and are pleased to share our progress update toward a first crewed flight later this year.

SpaceX was founded in 2002 with the express goal of safely and reliably launching humans to space, both low Earth orbit and beyond. Under our Commercial Crew Program partnership with NASA, this goal will soon become a reality. We understand the immense responsibility that comes with transporting NASA astronauts to space, and we are absolutely committed to building and operating the safest crewed system in history.

At this time, SpaceX has completed nearly all technical development required for the Falcon 9 / Crew Dragon transportation system. Over the course of this year, SpaceX will conduct final integration and testing to validate that the hardware and operating procedures for the launch vehicle, spacecraft, and associated ground systems meet or exceed all NASA safety requirements. The more than 6,000 employees of SpaceX are working hard every day to ensure we are the most reliable space launch provider in the world, and we will launch astronauts only when both we and NASA are ready to do so. Safely and reliably flying Commercial Crew missions for NASA remains the highest priority for SpaceX. While we acknowledge that the program has experienced some schedule delays, SpaceX has made major progress, and we are confident that we will safely fly astronauts this year. Importantly, delays in schedule have typically resulted from efforts to further address and reduce risk, and these delays have not resulted in program cost growth under the firm, fixed-price Commercial Crew contract.

Building upon the successful Commercial Cargo Program, NASA's use of innovative fixed-price public-private partnerships during the early stages of this program helped drive technology advances and reduce costs to the taxpayer. This competitive firm, fixed-price, performance-based model, as carried through the Commercial Crew Program, continues NASA's long-standing leadership in leveraging commercial practices and solutions to contribute to its mission. The National Aeronautics and Space Act of 1958, which established the agency, specifically identifies private sector collaboration as a core goal: "[t]o seek and encourage, to the maximum extent possible, the fullest commercial use of space."[1]

Under the Commercial Crew Program, as distinct from non-commercial development contracts, SpaceX designs, manufactures, and operates the crew system to meet a fixed set of high-level NASA requirements, and NASA has full insight every step of the way. This approach couples private sector innovation and

[1] Pub. L. 115–10, title III, §305(b), title IV, §443(b), Mar. 21, 2017, 131 Stat. 32, 47, added items 20148 and 20149.

capital with government investment and technical expertise. It has resulted in notable safety improvements, significant taxpayer savings, and more rapid development timeframes as compared to traditional cost-plus contracts with open-ended requirements. While development efforts for human space exploration are too often characterized by large and recurring cost overruns, the Commercial Crew Program remains on-budget by its very nature. Critically, we are rapidly restoring a national capability that America has not had since 2011 – the ability to carry humans into space and return them safely to Earth.

My testimony today will provide an overview of SpaceX's crew transportation system and an update on our development efforts. Together with NASA, we are honored to take the next step in building a safe, achievable, sustainable, and affordable human spaceflight program.

I. SpaceX Today

From its beginning, SpaceX has focused on dramatically improving the reliability, safety, and affordability of space transportation. We have successfully launched 46 Falcon 9 rockets since 2010 for a diverse set of customers, including NASA, the Department of Defense, commercial satellite operators, and allied international governments.

We design, manufacture, and launch within the United States, with a robust domestic supply chain of more than 4,400 American suppliers and partners. Notably, SpaceX does not have any significant reliance on foreign vendors or suppliers for systems or subsystems above the raw material level, including rocket engines. SpaceX manufactures the Merlin rocket engines used on Falcon 9 entirely in-house, and we have successfully launched more than 450 of them on orbital missions to date.

SpaceX routinely conducts critical uncrewed cargo resupply missions to and from the International Space Station (ISS) with our Dragon spacecraft, which was developed under the Commercial Cargo partnership with NASA. Recently, we successfully launched our 13th Dragon mission to ISS, and we are under contract for additional resupply missions through 2024. Later this year, SpaceX will fly NASA's Transiting Exoplanet Survey Satellite (TESS) and GRACE Follow-On missions.

SpaceX is also a certified provider of national security space launch under the Evolved Expendable Launch Vehicle (EELV) Program.

Commercially, SpaceX has restored the U.S. as a leader in global commercial satellite launch, taking back a majority of a market that had been wholly ceded to Russia and France for over a decade. With more than 70 missions under contract, SpaceX is the world's largest launch services provider.

SpaceX firmly believes that reusability is necessary to improve launch vehicle and spacecraft reliability and to reduce costs – goals consistent with the Commercial Crew Program. The company has self-invested significant funds toward the development and operation of reusable systems, beginning with early testing of our Grasshopper test platform at our McGregor, Texas Rocket Development Facility. In December 2015, SpaceX landed a Falcon 9 booster at Landing Zone 1 (LZ-1) at Cape Canaveral Air Force Station, Florida following an operational mission. This historic event was the world's first successful launch and landing of an orbital-class booster. Since then, SpaceX has landed 20 additional Falcon 9 first stage rockets, for a total of 9 landings at LZ-1 and 12 at sea on our autonomous spaceport droneships.

Reusability is a major advancement in flight reliability, since reusing boosters provides invaluable insight into the reliability of launch vehicle design and build, including inspection and analysis of hardware after it has flown. SpaceX is currently the only launch services provider that has the capability to review these data—a unique reliability feature of Falcon 9.

In addition to our progress on the Commercial Crew Program, 2017 was a year of many significant milestones for the company. In March, SpaceX achieved the world's first re-flight of an orbital-class booster when we successfully launched the commercial SES-10 satellite to a geostationary transfer orbit using a Falcon 9 rocket that had previously flown. Later in the year, SpaceX launched four other missions on flight-proven Falcon 9 launch systems, including the CRS-13 operational resupply flight for NASA to ISS in December, which also used a previously flown Dragon spacecraft. Other key milestones in 2017 include:

- 18 successful Falcon 9 launches, setting a new record for the number of launches in a year by an American provider, and moving the U.S. into top position for satellite launches for the first time since 2003;
- 14 successful Falcon 9 landings on 14 attempts;
- 4 successful resupply missions to ISS for NASA; and,
- 2 successful national security space launches, including the X-37B spaceplane and NROL-76.

In 2018, we anticipate an even higher flight rate, providing a wealth of data and experience to be applied to the Commercial Crew Program. We remain laser-focused on reliability and safety as we prepare to launch U.S. astronauts.

II. Overview of SpaceX's Commercial Crew System

SpaceX is designing, developing, testing, and certifying an end-to-end crew transportation system with NASA that includes both the proven Falcon 9 launch vehicle and the Crew Dragon spacecraft. SpaceX is responsible for all mission operations, including crew training, launch, on-orbit operations, and recovery. SpaceX Commercial Crew missions on Crew Dragon will include a mix of four NASA astronauts, powered cargo, and unpowered cargo. SpaceX is fully aware of the need to achieve a far higher level of safety and reliability for crew transportation than for any other type of mission.

Falcon 9 Launch Vehicle

Falcon 9 is a two-stage, partially-reusable launch system designed and built by SpaceX at our Hawthorne, California headquarters. Since first flight in 2010, Falcon 9 has successfully flown 46 times, including 18 launches in 2017. Falcon 9 is the only operating launch system in the world with reusability capabilities. Following successful launches, the Falcon 9 first stage can return either to an offshore autonomous spaceport droneship or a ground-based landing zone. To date, Falcon 9 has successfully landed 21 times and been re-launched five times.

The vehicle has been designed from day one with robust margins and advanced safety systems to support astronaut flights. Falcon 9 has numerous reliability features that go well beyond any other launch vehicle currently flying, including a failure detection, isolation, and recovery (FDIR) system, single and multiple engine-out capability, minimal separation events, and a hold-before-release system. SpaceX uses a common configuration, with periodic safety and performance enhancements, for all Falcon 9 missions to provide the same high level of reliability for astronaut transportation, critical national security missions, and commercial satellite carriage. SpaceX does not require any extra safety features or performance capability "bolted on" to support crew program requirements. This approach helps ensure a much longer flight pedigree and confidence in vehicle reliability.

SpaceX also achieves safety and reliability on Falcon 9 through our rigorous processes. Our system safety experts provide accurate and comprehensive products such as failure modes, effects, and criticality analyses; hazard analyses; and probabilistic safety analyses. We have been certified to conduct launches by both NASA (Commercial Resupply Services Program and Launch Services Program) and the U.S. Air Force (Evolved Expendable Launch Vehicle Program).

Crew Dragon Spacecraft

Crew Dragon will be the safest crewed spacecraft in history by incorporating robust and redundant flight systems and advanced fault detection and escape capabilities, as well as by leveraging SpaceX's flight heritage and comprehensive safety culture. The spacecraft is a fully autonomous rendezvous and docking vehicle with manual override capability in case of crew need. The crew-configured spacecraft builds upon Dragon's 14 successful flights to and from orbit since 2010, including 13 trips to ISS. Like Falcon 9, Crew Dragon is inherently reusable, offering the potential to reduce costs to NASA and providing additional margin through robustness of design to further minimize risks during flight. Each spacecraft is built to support 210 day missions to ISS, including launch, docking, on-orbit standby, return, and recovery.

SpaceX has significant real-world flight experience on most of Crew Dragon's systems. The main propulsion system, structures, avionics, software, guidance, navigation, and control (GNC) systems, on-orbit propulsion systems, basic Environmental Control and Life Support Systems (ECLSS), parachute systems, mission control, ground processing, vehicle integration, and ISS integration all have been proven under the Commercial Cargo Program. Under Commercial Crew, SpaceX is evolving these existing systems, analyses, processes, and infrastructure to achieve a new level of safety and reliability for human flight. These upgrades include an expanded pressurized cabin volume, strengthened spacecraft structures, enhanced parachute capability, and conformal trunk body-mounted solar cell modules (instead of the current deployable articulating solar arrays).

The most significant upgrades to the spacecraft are the enhanced ECLSS and the Launch Escape System (LES). Building off the proven ECLSS technology in Dragon's cargo configuration for live animal transport, Crew Dragon is designed to reliably meet the greater demands of human passengers. SpaceX also added significant margin to ensure the life support system would be able to support a full crew, even for contingency mission profiles.

The LES architecture is designed to propel the spacecraft away from Falcon 9 in the event of a contingency. Previous generation systems utilized a separate rocket tower mounted on top of the spacecraft. This system was jettisoned after several minutes into flight, leaving crew without escape capability for the remainder of the trip to orbit. SpaceX's launch escape system, however, is integrated directly into the spacecraft, enabling Crew Dragon to maintain escape capability from the launch pad all the way to orbit, which no spacecraft in history has possessed. Our integrated LES represents a major advance in the safety of human spaceflight systems.

III. Cargo Dragon Program

Crew Dragon builds upon the successful Dragon spacecraft, which was developed in close partnership with NASA under the Commercial Orbital Transportation Services (COTS) Program.

In 2006, NASA competitively awarded SpaceX a COTS Space Act Agreement (SAA) that ultimately represented $396 million of NASA investment, primarily focused on development of the Dragon cargo capsule and two demonstration flights. SpaceX self-invested more than $500 million (at that time) in the development of the Falcon 9, including launch sites, production, and test facilities.[2] Just four years later in December 2010—an unprecedented reduction in development time for a complex space system—SpaceX flew Dragon to orbit and safely returned it from space, becoming the first commercial company in history to successfully do so.

[2] SpaceX has continued to invest in reliability, performance, and reusability enhancements for Falcon 9.

Like the Commercial Crew Program, the COTS Program established high-level requirements and encouraged contractors to execute against them with creative, innovate, and cost-effective solutions, reducing "requirements creep" and encouraging new thinking. The COTS Program was the first of its kind for NASA: a "pay for performance" partnership between the government and private business to rapidly design and prototype critical technologies. NASA structured the COTS Program as a collaborative venture with commercial space companies – sharing the risks, costs, and rewards of developing new space transportation capabilities. The NASA-SpaceX COTS partnership successfully enabled and promoted genuine innovation while maintaining safety and reliability standards.

In May 2012, Dragon launched to ISS and became the first commercial spacecraft in history to berth with the orbiting laboratory. Shortly thereafter in October 2012, SpaceX conducted the first operational mission under the follow-on fixed-price Commercial Resupply Services (CRS) contract, ending America's reliance on Russia and other nations for cargo missions. To date, SpaceX has successfully delivered 59,000 pounds of critical cargo, science experiments, and other supplies to ISS and has returned more than 40,000 pounds back to Earth under the CRS contract. Dragon is the only operational spacecraft in the world today that has the capability to return a significant amount of cargo from space. All of these missions have been procured under a firm, fixed-price, pay-for-performance contract with NASA.

In June 2017, Dragon made history again by becoming the first commercial spacecraft to fly to orbit more than once. The CRS-11 spacecraft used on this mission had previously flown on the CRS-4 mission in 2014. In December 2017, SpaceX launched the CRS-13 mission, which used the same Dragon spacecraft that had flown on the CRS-6 mission in 2015.

IV. Commercial Crew Program History

SpaceX and NASA first entered into the Commercial Crew partnership in 2011. Since then, SpaceX has completed most of the development work for the Crew Dragon spacecraft under three competed firm, fixed-price, milestone-based program phases.

- **Commercial Crew Development Round 2 (CCDev-2).** In April 2011, NASA awarded SpaceX an SAA to mature the development of key systems required to modify the Dragon spacecraft to carry crew. Most notably, much of SpaceX's effort under this program focused on the integrated SuperDraco LES. SpaceX also completed substantial design and development work on other key systems, including the ECLSS and the development of a crew cabin prototype. SpaceX completed all 10 program milestones by August 2012.

- **Commercial Crew Integrated Capability (CCiCap).** In August 2012, NASA awarded SpaceX a firm, fixed-price SAA with the objective of producing a detailed design of the entire crew transportation system. SpaceX completed a number of major milestones as part of this effort, including multiple parachute tests with drop articles, a safety review of the system, and a Pad Abort test.

- **Commercial Crew Transportation Capability (CCtCap).** NASA awarded SpaceX a FAR-based firm, fixed-price contract in September 2014 to complete development of the Crew Transportation System. This contract includes numerous key technical and certification milestones, an uncrewed flight test, a crewed flight test, and six operational missions following system certification. CCtCap is the current and final development phase of the Commercial Crew Program.

V. Crew Dragon Program Achievements

Leveraging the success of the Dragon program, SpaceX has achieved a number of significant Crew Dragon development milestones as the crew system advances toward first flight. Under the current fixed-price contract, SpaceX has completed nearly all system development, including the Critical Design Review

(CDR), with no program budget growth, as detailed below.

- **Launch Escape System.** SpaceX has made major progress toward readying the spacecraft's LES. The LES incorporates eight SuperDraco engines, which together produce 120,000 pounds of axial thrust in the event of a contingency. Key milestones include:

    - **April 2011:** Design of the SuperDraco engines began.

    - **June 2012:** Passed Concept Baseline Review for this system and began conducting extensive static fire testing of engine components at our test facility in McGregor, Texas.

    - **July 2014:** Concluded full-scale, flight-ready SuperDraco hot-fire engine qualification testing for the Pad Abort vehicle.

    - **May 2015:** Conducted successful Pad Abort test. For this major milestone, SpaceX integrated the full LES, including all eight engines, into a flight article in order to demonstrate the system's capabilities. This crucial real-world test simulated a launch pad emergency that would require rapid escape of the flight crew. The full-scale spacecraft used included a flight-like propulsion system, primary structure, avionics system, and parachute system to demonstrate integrated escape and recovery systems. Within a fraction of a second of receiving the abort command, Dragon's SuperDracos reached full thrust and pushed the spacecraft away from the launch site. The spacecraft reached an altitude of over a kilometer before deploying its parachutes and safely splashing down in the Atlantic Ocean, as intended.

    - **December 2015:** Completed a successful propulsive hover test to demonstrate precision control and capsule environments survivability for continued refinement of the escape system's capabilities.

    - **September 2017:** Completed first round of SuperDraco engine qualification in support of human spaceflight certification.

    - **December 2017:** Completed hot-fire acceptance testing of all SuperDraco engines to be flown on the first flight of Crew Dragon to ISS.

- **Life Support System.** Crew Dragon's life support system ensures a safe voyage for crew during both nominal and unlikely off-nominal flights. Over the past several years, SpaceX has conducted significant design and development of this capability at the component and system levels.

    - **October 2016:** Built a full-scale test article of the spacecraft with flight ready life support systems, known as the ECLSS Module, to evaluate and observe Crew Dragon as it autonomously controls the cabin environment. The ECLSS module includes all of the complex components required for a mission to space, including pressure control, temperature control, humidity control, air quality monitoring, contaminants control, and waste containment.

    - **November 2016**: Completed functional testing of the ECLSS Module. As part of this testing regime, SpaceX environmental engineers were sealed inside the ECLSS Module and evaluated its performance during a variety of flight-like conditions.

- **Space Suits.** Space suits are also a crucial component of Crew Dragon's safety systems. SpaceX is designing and building intravehicular activity suits designed to protect crew during flight and upon recovery. Each suit provides breathable air, waste control, and pressure control to a crew member in the event of a contingency during flight or on-orbit. SpaceX has worked closely with industry experts and NASA astronauts to design a system that is easy to use and provides high levels of safety, movement, and comfort.

    - **November 2016:** Completed a key space suit qualification milestone following numerous human-in-the-loop tests with NASA astronauts and SpaceX personnel to verify these suits and their operability within the spacecraft. Testing included wearing the suit while in a vacuum chamber to validate performance.

- **Recovery Operations.** SpaceX is responsible for the safe recovery of the NASA crew following their departure from ISS. While SpaceX has successfully returned 14 Dragon spacecraft from orbital missions since 2010, SpaceX is conducting an independent test regime to qualify and verify the enhanced parachute systems on the Crew Dragon spacecraft.

    - **December 2016:** Completed initial parachute system testing following five drop tests.

    - **June 2017:** First ocean recovery tests complete. After Crew Dragon returns from a successful flight to ISS, it will splash down softly in the Atlantic Ocean off the Florida coast. During these real-world tests, SpaceX used a full-sized spacecraft model in the Indian River in Florida, where SpaceX employees, the U.S. Coast Guard, and Air Force pararescue experts refined recovery procedures.

    - **December 2017:** Completed the first round of qualification testing for the parachute system.

- **Spacecraft Manufacturing.** SpaceX has completed three full-scale Crew Dragon units, including a qualification module, the ECLSS Module, and the Pad Abort vehicle. Currently, four Crew Dragon units are undergoing production and test: the two spacecraft for uncrewed and crewed flight tests, and two additional spacecraft for subsequent operational missions. In September 2017, SpaceX integrated the uncrewed test flight article pressure section with the service section – a major step toward the operational flight vehicle.

- **Astronaut Training.** SpaceX is working closely with NASA to train the first four NASA astronauts selected for the Commercial Crew Program in Crew Dragon operations and flight procedures. This training also encompasses pre-flight and post-flight activities, such as donning and removing suits and vehicle ingress and egress.

    - **August 2017:** Conducted rescue and recovery training with recovery professionals and NASA astronauts in full SpaceX spacesuits in the Atlantic Ocean to simulate a return from orbit.

    - **October 2017:** NASA astronauts began practicing with SpaceX space suits inside spacecraft mockup, demonstrating suit donning, gloved hand operations with panels and displays, pressurized fit, general ergonomics, and other human factors.

- **Mission Operations.** Ground operators and mission crew monitor all critical systems and data to understand vehicle behavior during all phases of a mission from pre-launch to return. The SpaceX

mission operations team has roles to represent all of the critical subsystems in each vehicle and ground system and to maintain a strategic view, mindful of overall mission priorities and potential threats to safety and mission success as the flight progresses. The flight crew has the monitoring, command, and control capabilities necessary to ensure safety and mission success. SpaceX mission operations personnel, in joint simulations with NASA, are currently undergoing training for the uncrewed and crewed demonstration flights to ISS.

  - **October 2017:** Conducted the first Flight Operations Review and baselined a series of flight rules and joint operations.
  - **November 2017:** Conducted an Integrated Systems Review where SpaceX and NASA jointly evaluated the Dragon ground, ascent/docking, docked phase, and de-orbit/re-entry/landing concept of operations.

- **Launch Pads and Ground Systems.** SpaceX has been enhancing the ground systems and associated capabilities at our sites at Cape Canaveral, Florida to support Commercial Crew missions.
  - **February 2017:** First SpaceX launch out of the historic Launch Complex 39A (LC-39A) within Kennedy Space Center, following more than $100 million of company investment. This site served as the primary launch facility for both the Apollo and Space Shuttle programs. SpaceX will install the crew access arm to this site in spring 2018.
  - **December 2017:** Established dedicated Crew Dragon processing, maintenance, and refurbishment facilities within Cape Canaveral Air Force Station.

VI. Remaining Major Commercial Crew Milestones

SpaceX is on track to complete several key milestones in 2018 ahead of operational missions, including additional parachute qualification testing and further recovery operations testing.

Most importantly, SpaceX will soon finish manufacturing the first two flight-ready Crew Dragon spacecraft to be used on the uncrewed and crewed demonstration missions to ISS. Once complete, these spacecraft will be transferred to SpaceX's facilities in Cape Canaveral, Florida for pre-flight processing and preparation for three major tests:

- **Flight to ISS without Crew.** This end-to-end test involves launching an uncrewed Crew Dragon to ISS, autonomously docking it with ISS, and safely recovering it at the end of the mission. The full system will be exercised in an identical mission profile as that of a crewed mission. This flight will include launch, rendezvous, approach and docking, departure, entry, and landing. In effect, this mission will demonstrate that the Crew Dragon, Falcon 9, ground segment, and mission operations elements can perform the operational mission.
- **In-Flight Abort Test.** This uncrewed test will validate that the Crew Dragon LES can safely carry crew away from the launch vehicle during even the most challenging moment of flight when aerodynamic forces reach peak intensity.
- **Flight to ISS with Crew.** During this demonstration mission, two NASA astronauts will launch aboard Crew Dragon to ISS and return to Earth following a short stay on a flight profile similar to operational flights. This is the last major milestone before operational flights begin.

VI. SpaceX Safety and Mission Assurance

SpaceX is committed to safe ground and flight operations for all of our missions, and particularly crew transportation. We are working shoulder to shoulder with NASA to ensure that our operations meet or exceed the very high requirements of NASA's human spaceflight program. All of this work is part of a comprehensive human rating certification process, and these discussions will continue as the SpaceX system is completed.

SpaceX's mission assurance practices, managed by the Build and Flight Reliability organization within the company, encompass every aspect of the launch vehicle, spacecraft, ground systems, and associated operations from early design continuing through operational flights. SpaceX uses a continuous risk management process, whereby risks are identified, analyzed, tracked, mitigated, and documented through the lifecycle of a product or mission campaign.

In addition to full systems analyses, real-world testing is critical to mission assurance at SpaceX. Both the Falcon 9 and Crew Dragon undergo an exhaustive series of tests, from the component to the vehicle system level. This testing includes component-level qualification and workmanship testing; structures, flight system, and propulsion subsystem testing; and first- and second-stage full system testing. In addition to testing to environmental extremes (plus margin), we test all hardware to account for off-nominal conditions. Because SpaceX uses a common launch vehicle hardware and software configuration for all flights, no new or unproven systems will be used on Commercial Crew flights. The Falcon 9 configuration that will fly NASA astronauts will also be flying for many other customers each year. This approach of consistent hardware and software buys down risk through scale. For example, SpaceX has successfully launched Falcon 9 46 times and has conducted more than 5,600 engine tests at our SpaceX Rocket Development Facility in McGregor, Texas.

SpaceX is keenly aware and deeply appreciative of NASA's significant institutional and technical knowledge with regard to human spaceflight safety. SpaceX collaborates with NASA to incorporate these lessons into the crew transportation system. SpaceX manages weekly, monthly, and quarterly risk review meetings with program officials to provide key insight into any potential risks and the steps SpaceX is taking to mitigate them. Furthermore, since SpaceX manufactures the majority of every launch vehicle, including every rocket engine, NASA has meaningful access to all design, build, and test data for the vehicle and does not need to rely on requests to foreign partners for mission assurance.

NASA has visibility into not only the specific Falcon 9 vehicles being used for the program, but also those for every SpaceX launch. With SpaceX's robust manifest, NASA has access to a large data set to fully understand all system performance over time.

SpaceX and Commercial Crew Program engineers continue to work collaboratively to identify and mitigate any possible concerns. For example, a very small number of SpaceX turbopumps experienced some minor cracking, a common occurrence with many rocket engines including those that flew on the Space Shuttle. These cracks were within engine design constraints and would not have posed a risk to flight. Both NASA and the Air Force were comfortable with them for satellite launches. However, for crew flights, NASA requested that SpaceX eliminate cracking as an extra measure of mission assurance. We have since addressed this concern with design changes and validation tests, and we fully expect our Merlin engines will meet NASA's robust crew safety requirements.

At SpaceX, every design and operation decision is driven by safety and reliability. SpaceX recognizes that some proposed operating procedures for the crew transportation system differ from those on the Space Shuttle Program. SpaceX has elected to adopt certain approaches, including propellant loading after astronauts have been secured in the spacecraft and the launch escape system is enabled, because they offer

the potential to improve safety for both astronauts and ground crew. Under SpaceX's operations plan, after astronauts board the spacecraft, the ground crew will close out the vehicle and will leave the launch site. Launch vehicle propellant loading will begin only after the escape system is armed. This approach ensures that astronauts have escape capability during any time propellant is on the launch vehicle, and it does not expose ground crew to unnecessary risk. Notably, the Space Shuttle continued loading liquid hydrogen for three hours ("Space Shuttle Replenish" procedure) after astronauts were aboard; propellant loading on Falcon 9 consumes approximately 30 minutes, reducing the time astronauts are exposed to loading operations.

We have also worked closely with NASA to further enhance the robustness of our composite overwrapped pressure vessels (COPVs) and to ensure NASA is comfortable with their performance in a variety of flight environments. We are confident that this process is safe, and we are working closely with NASA to complete the ongoing, rigorous analysis necessary to achieve certification.

Finally, in 2012 SpaceX established an Independent Safety Advisory Panel composed of leading human spaceflight safety experts, including several former NASA astronauts and senior NASA officials. The panel has provided independent and objective assessments of the safety of SpaceX's crew transportation system for human spaceflight to help SpaceX maintain the highest commitment to safety.

*****

SpaceX appreciates the invitation to testify before the Committee today. We are honored to partner with NASA to safely, routinely, and reliably launch America's next generation of astronauts to space, and we look forward to returning human spaceflight to the United States later this year.

Dr. Hans Koenigsmann
Vice President of Build and Flight Reliability

Dr. Hans Koenigsmann leads the Build and Flight Reliability Team at SpaceX. In this role he is the executive leader of SpaceX's quality engineering and process development teams and, oversees the launch readiness process during launch campaigns. He provides an independent assessment of launch risks, identifying and resolving anomalies during integration and launch itself. The Reliability teams resolve all major anomalies, evaluate and mitigate risk and perform hazard analyses and other functions on the vehicle system level.

He has more than 25 years of experience designing, developing and building complex avionics and guidance, navigation and control (GNC) systems for launch vehicles and satellites. As a member of SpaceX from the company's inception in 2002, Hans built up the avionics, software and GNC departments and developed the launch readiness process currently in use during each launch campaign. He also designed the SpaceX risk mitigation process and initiated the risk database, establishing a similar process for system-level changes to the vehicle and ground systems. Dr. Koenigsmann was the Chief Avionics Architect of the Falcon 1 and early Falcon 9 efforts, and he is a key member of the small, core group of SpaceX engineers responsible for operating these vehicles on the launch pad and in orbit. He served as Launch Chief Engineer for the last 3 Falcon 1 missions and for most Falcon 9 flights to date.

Hans' experience includes the development of two suborbital and two orbital launchers, as well as several satellite projects and attitude control systems. He served as head of the Space Technology Division of Germany's ZARM at the University of Bremen, where he was responsible for the development and operation of the satellite BREM-SAT. Following this experience, Hans worked for Microcosm as Chief Scientist and Flight Systems Manager for their suborbital vehicles.

Hans has a Ph.D. in Aerospace Engineering and Production from the University of Bremen and a Master of Science in Aerospace Engineering from the Technical University of Berlin.

About SpaceX

SpaceX designs, manufactures, and launches the world's most advanced rockets and spacecraft. The company was founded in 2002 by Elon Musk to revolutionize space transportation, with the ultimate goal of enabling people to live on other planets. Today, SpaceX is advancing the boundaries of space technology through its Falcon launch vehicles and Dragon spacecraft. SpaceX is a private company owned by management and employees, with minority investments from Founders Fund, Draper Fisher Jurvetson, and Valor Equity Partners. The company has more than 4,000 employees at its headquarters in Hawthorne, California; launch facilities at Cape Canaveral Air Force Station, Florida, and Vandenberg Air Force Base, California; a rocket-development facility in McGregor, Texas; and offices in Houston, Texas; Chantilly, Virginia; and Washington, DC. For more information, visit www.spacex.com.

SPACEX

Chairman BABIN. Thank you very much, Dr. Koenigsmann. I'd like to now recognize Ms. Chaplain for five minutes to present her testimony.

TESTIMONY OF MS. CRISTINA CHAPLAIN, DIRECTOR, ACQUISITION AND SOURCING MANAGEMENT, U.S. GOVERNMENT ACCOUNTABILITY OFFICE

Ms. CHAPLAIN. Chairman Babin, Ranking Member Bera, Chairman Smith, Ranking Member Johnson, thank you for inviting me today to discuss NASA's Commercial Crew Program. GAO has been assessing the progress of commercial crew for several years. In the past we've also reviewed the commercial cargo program known as COTS as well as NASA's human spaceflight programs.

As you know, NASA's acquisition strategy on the Commercial Crew Program is similar to the one it used on COTS but different than every other spacecraft it has built for humans. For commercial crew, each contractor develops, owns, and operates its spaceflight systems. The contractors have access to NASA expertise and resources throughout development process, but NASA engineers are not making design decisions and NASA personnel are less involved in processing, testing, launching, and operating the crew transportation system. In the end, NASA will buy a crew transportation service much like it does for the station's cargo.

While Boeing and SpaceX are making significant progress, both continue to experience schedule delays. It has been three weeks since the program's original December 2017 goal to secure domestic access to the space station, yet neither contractor has yet to conduct a test flight. In fact, final certification dates have slipped to the first quarter of calendar year 2019. And we found that the program's own analysis indicates that certification is likely to slip into December 2019 for SpaceX and February 2020 for Boeing.

Several factors could contribute to additional delays to the schedules presented here today. One, the contractor schedules have been aggressive from the onset of the program. To date, Boeing has reported a delay six times, and SpaceX has reported a delay nine times for at least one key event. According to NASA, both contractors assume an efficiency factor in getting to the crewed flight test that the program office does not assume in its schedule.

The contractors also use their schedule dates to motivate their teams while NASA adds additional schedule margin for testing.

Aggressive schedules and delays are not atypical for programs developing new launch vehicles and/or crew vehicles, and we see them on all types of contracts. But in this case, the delays and uncertain final certification dates raise questions about whether the U.S. will have uninterrupted access to the space station beyond 2019. NASA may have to purchase additional Soyuz seats, but as Mr. Gerstenmaier mentioned, there are limits to how it can do so. Further, these delays may lessen NASA's return on investment with its contractors.

There are also programmatic and safety risks that may result in more delays. Again, not unusual for programs of this nature, even at this stage of development. Boeing, for example, is addressing the risk that the Starliner's heat shield could damage the parachute system during reentry into the earth's atmosphere.

SpaceX needs to address concerns about its plans to fuel the launch vehicle after astronauts are on board.

In addition, both contractor systems must meet a standard for crew safety that is much higher than that for the shuttle. A considerable amount of work remains to be done to determine whether the contractors will meet this requirement.

Lastly, NASA's program office could also face delays and workload problems that can cause delays. Program officials told GAO that one of their greatest upcoming challenges would be to complete two oversight activities concurrently. These include conducting phased safety reviews and verifying that contractors meet requirements.

The program's ability to smooth its workload is limited as the contractors control their own schedules. Last year, though, we found that the proposed schedule changes could alleviate some overlap in terms of the program office's workload.

We will be further assessing the Commercial Crew's Program schedule and risk as well as issues surrounding safety and look forward to reporting on the results of our work later this year.

Chairman Babin and Ranking Member Bera, this concludes my statement, and I'm happy to answer any questions you have.

[The prepared statement of Ms. Chaplain follows:]

United States Government Accountability Office

GAO

Testimony

Before the Subcommittee on Space, Committee on Science, Space, and Technology, House of Representatives

For Release on Delivery
Expected at 10:00 am ET
Wednesday, January 17, 2018

NASA COMMERCIAL CREW PROGRAM

Continued Delays Pose Risks for Uninterrupted Access to the International Space Station

Statement of Cristina T. Chaplain
Director, Acquisition and Sourcing Management

GAO Highlights

Highlights of GAO-18-317T, a testimony before the Subcommittee on Space, Committee on Science, Space and Technology, House of Representatives

Why GAO Did This Study

Since the Space Shuttle was retired in 2011, the United States has been relying on Russia to carry astronauts to and from the space station. NASA's Commercial Crew Program is facilitating private development of a domestic system to meet that need safely, reliably, and cost-effectively before the seats it has contracted for on a Russian spacecraft run out in 2019.

In 2014, NASA awarded two firm-fixed-price contracts to Boeing and SpaceX worth a combined total of up to $6.8 billion to develop crew transportation systems and conduct initial missions to the space station. In February 2017, GAO found that both contractors had made progress, but their schedules were under mounting pressure.

This statement provides preliminary observations on the extent to which the contractors and the program are making progress toward meeting NASA's standards for human spaceflight, a process called certification.

This statement is based on ongoing work and information contained in GAO's February 2017 report on this program (GAO-17-133). To do this work, GAO analyzed contracts, schedules, and other documentation.

What GAO Recommends

GAO is not making any new recommendations. In February 2017, GAO recommended that NASA develop a contingency plan to maintain access to the ISS beyond 2019, when its contract with Russia for seats on the Soyuz was scheduled to end. NASA agreed with this recommendation and purchased Soyuz seats through 2019.

View GAO-18-317T. For more information, contact Cristina T. Chaplain at (202) 512-4841 or chaplainc@gao.gov.

January 17, 2018

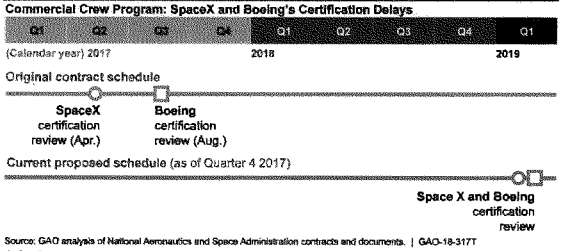
NASA COMMERCIAL CREW PROGRAM

Continued Delays Pose Risks for Uninterrupted Access to the International Space Station

What GAO Found

Both Boeing and Space Exploration Technologies (SpaceX) are making progress toward their goal of being able to transport American astronauts to and from the International Space Station (ISS). However, both continue to experience schedule delays. Such delays could jeopardize the ability of the National Aeronautics and Space Administration's (NASA) Commercial Crew Program to certify either company's option—that is, to ensure that either option meets NASA standards for human spaceflight—before the seats the agency has contracted for on Russia's Soyuz spacecraft run out in 2019. (See figure.)

Commercial Crew Program: SpaceX and Boeing's Certification Delays



Source: GAO analysis of National Aeronautics and Space Administration contracts and documents. | GAO-18-317T

GAO's ongoing work has identified three key risks, which are consistent with challenges reported in February 2017 that could further delay certification of each contractor's crew transportation system:

- **Aggressive schedules**—NASA, Boeing, SpaceX, and independent review bodies have all noted that the contractors' schedule plans are aggressive. The anticipated schedule risks have since materialized.
- **Programmatic and safety risks**—SpaceX and Boeing are addressing technical risks, which is not uncommon for NASA projects as they often push the state of the art in space technology. In addition, the contractors' systems must meet a standard for crew safety. Additional work remains to determine whether the contractors will meet this requirement.
- **Program office workload**—Program officials told GAO that one of their greatest upcoming challenges will be to complete two oversight activities—conducting phased safety reviews and verifying that contractors meet requirements—concurrently. The program's ability to smooth its workload is limited, as the contractors generally control their development schedules. In February 2017, GAO found that proposed schedule changes could alleviate some overlap.

Delays and uncertain final certification dates raise questions about whether the United States will have uninterrupted access to the ISS after 2019, and may lessen NASA's return on investment with the contractors. GAO will continue to assess the contractors' and program's progress.

Chairman Babin, Ranking Member Bera, and Members of the Subcommittee:

I am pleased to be here today to discuss the status of the National Aeronautics and Space Administration's (NASA) Commercial Crew Program. As you know, following the retirement of the Space Shuttle in 2011, the United States was left with no domestic ability to provide crew access to the International Space Station (ISS). Since then, NASA has relied on purchasing seats from Russia on its Soyuz spacecraft to maintain a U.S. presence on the station. NASA's Commercial Crew Program is intended to end this dependency by facilitating the commercial development of a crew transportation system that can provide safe, reliable, and cost-effective transportation to and from low earth orbit, including the ISS. NASA's goal is to have one or more contractors that can provide crew transportation services to the ISS, which NASA expects will be operational until at least 2024.

NASA's acquisition strategy on the Commercial Crew Program is similar to the one it used on the Commercial Cargo program, but different than every other spacecraft it has built for humans, from Mercury to Gemini and Apollo to the Space Shuttle. For the Commercial Crew Program, each contractor designs, develops, builds, owns, and operates its spaceflight system and infrastructure. The contractors have access to NASA's expertise and resources throughout the development process, but NASA engineers are not making design decisions, and NASA personnel are less involved in processing, testing, launching, and operating the crew transportation system. In the end, NASA will buy a crew transportation service—a ride for its astronauts to and from the ISS—much like it does for ISS cargo.

In the most recent phase of the Commercial Crew Program, NASA awarded firm-fixed-price contracts in 2014 to Boeing and Space Exploration Technologies Corporation (SpaceX), valued at up to $4.2 billion and $2.6 billion, respectively, for the development of crew transportation systems that meet NASA requirements and for flying initial missions to the ISS. According to the contracts, the companies were supposed to provide NASA all the evidence the agency needed to certify that their systems met its performance and safety requirements by 2017.

We have reviewed the Commercial Crew Program for the last two years as part of our annual assessment of all NASA's major projects.[1] We also issued a report on the program in February 2017 in response to a provision in the House Committee on Appropriations report accompanying H.R. 2578.[2] Prior to this, we issued a report in December 2011 that assessed NASA's acquisition approach for acquiring commercial crew transportation.[3] Over this time, we have reported that the program made progress as both contractors make progress finalizing their designs and building hardware, but we also found that schedule pressure has increased as contractors delay key events.[4]

My statement today provides our preliminary observations on the extent to which the contractors and the Commercial Crew Program are making progress in developing crew transportation systems that meet NASA's standards for human spaceflight, a process called certification. This statement today is based upon our most recent report issued in February 2017 and some updated information since that report was published, which is based on ongoing work.[5] Our ongoing work is in response to a provision included in the house report accompanying H.R. 5393 for GAO to review the progress of NASA's human exploration programs.

For our ongoing work, to assess the extent to which the contractors are making progress toward certification, we obtained and reviewed program and contractor documents, including quarterly updates as well as monthly schedule summaries, from April 2017 through November 2017. We interviewed contractor officials to discuss the contractors' recent progress as well as their upcoming events and any expected delays. To identify total delays to date, we compared original contract schedules to Boeing's October 2017 working schedule and SpaceX's November 2017 working schedule, which identify their most recent proposed delays to some

[1]GAO, *NASA: Assessments of Major Projects*, GAO-17-303SP (Washington, D.C.: May 16, 2017); and *NASA: Assessments of Major Projects*, GAO-16-309SP (Washington, D.C.: Mar. 30, 2016).

[2]GAO, *NASA Commercial Crew Program: Schedule Pressure Increases as Contractors Delay Key Events*, GAO-17-137 (Washington, D.C.: Feb. 16, 2017).

[3]GAO, *National Aeronautics and Space Administration: Acquisition Approach for Commercial Crew Transportation Includes Good Practices, but Faces Significant Challenges*, GAO-12-282 (Washington, D.C.: Dec. 15, 2011).

[4]GAO-17-137.

[5]GAO-17-137.

milestones. We also identified key risks facing the contractors and program by obtaining and reviewing monthly and quarterly reports, as well as the risks tracked in the program's risk management system, from April 2017 through November 2017. We interviewed program and contractor officials with knowledge of the technical risks to understand the risks and potential impacts and how they are planning to mitigate those risks.

The work upon which this statement is based is being conducted in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives. More information about the scope and methodology for our February 2017 report can be found in that report.

We plan to issue a final report on the Commercial Crew Program in spring 2018. NASA provided us technical comments on information that is included in this statement, which we incorporated as appropriate.

Background

NASA's Commercial Crew Program is a multi-phased effort that began in 2010. Across the five phases, NASA has engaged several companies using both agreements and contract vehicles to develop and demonstrate crew transportation capabilities. As the program has passed through these phases, NASA has generally narrowed down the number of participants. The early phases of the program were under Space Act agreements, which is NASA's other transaction authority.[6] These types of agreements are generally not subject to the Federal Acquisition Regulation (FAR) and allow the government and its contractors greater flexibility in many areas. Under these Space Act agreements, NASA relied on the commercial companies to propose specifics related to their crew transportation systems, including their design, the capabilities they would provide, and the level of private investment. In these phases, NASA provided technical support and determined if the contractors met certain technical milestones. In most cases, NASA also provided funding.

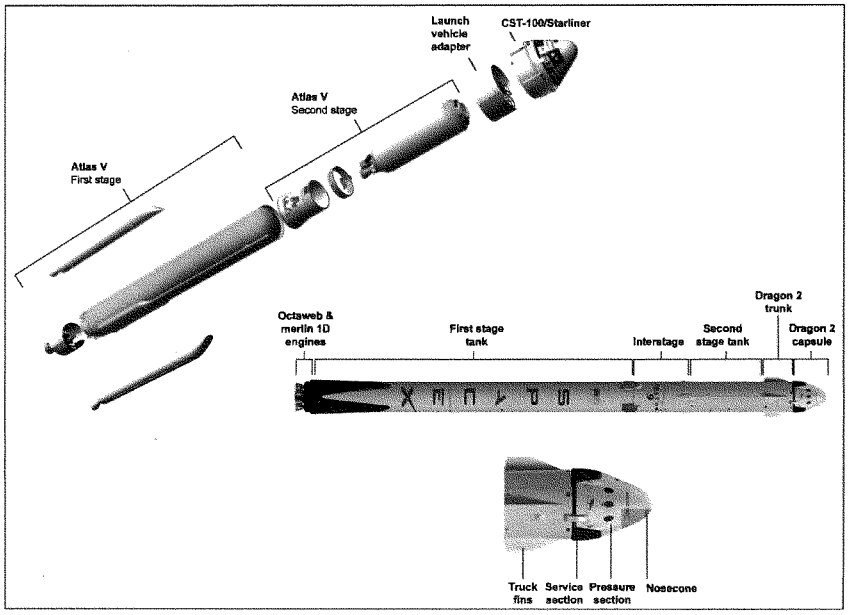
[6]This authority allows an agency to enter into agreements "other than" standard government contracts or other traditional mechanisms.

For the final two phases of the program, NASA awarded FAR-based contracts. By using FAR-based contracts, NASA gained the ability to levy specific requirements on the contractors and procure missions to the ISS, while continuing to provide technical expertise and funding to the contractors. Under these contracts, NASA will also evaluate whether contractors have met its requirements and certify their final systems for use.

In September 2014, NASA awarded firm-fixed-price contracts to Boeing and SpaceX, valued at up to $4.2 billion and $2.6 billion, respectively, for the Commercial Crew Transportation Capability phase. Under a firm-fixed-price contract, the contractor must perform a specified amount of work for the price negotiated by the contractor and government. This is in contrast to a cost-reimbursement contract, in which the government agrees to pay the contractor's reasonable costs regardless of whether work is completed. Thus, under the fixed-price contracts, the contractors must generally bear the risk of cost overruns or schedule delays.

During this phase, the contractors will complete development of crew transportation systems that meet NASA requirements, provide NASA with the evidence it needs to certify that those systems meet its requirements, and fly initial crewed missions to the ISS. Under the contracts, NASA and the companies originally planned to complete the certification review for each system by 2017. Figure 1 shows the spacecraft and launch vehicles for Boeing and SpaceX's crew transportation systems.

Figure 1: Boeing and SpaceX Crew Transportation Systems



Source: Copyright © 2016 United Launch Alliance, LLC. (top image); ©2016 SpaceX (bottom image). | GAO-18-317T

The Commercial Crew Transportation Capability phase contracts include three types of services:

- **Contract Line Item 001** encompasses the firm-fixed-price design, development, test, and evaluation work needed to support NASA's final certification of the contractor's spacecraft, launch vehicle, and ground support systems.

- **Contract Line Item 002** covers any service missions that NASA orders to transport astronauts to and from the ISS. Under this indefinite-delivery, indefinite-quantity line item, NASA has ordered six missions from each contractor.[7] Each service mission is its own firm-fixed-price task order. NASA must certify the contractors' systems before they can fly these missions.
- **Contract Line Item 003** is an indefinite-delivery, indefinite-quantity line item for any special studies, tests, and analyses that NASA may request. These tasks do not include any work necessary to accomplish the requirements under contract line item 001 and 002. As of July 2017, NASA had issued four orders under this contract line item to Boeing, worth approximately $1.8 million, including an approximately $180,000 study of the spacecraft's seat incline. NASA has issued one order under this contract line item to SpaceX, which did not affect the value of this line item. The maximum value of this contract line item is $150 million.

NASA divided the certification work under contract line item 001 into two acceptance events: the design certification review and the certification review. An acceptance event occurs when NASA approves a contractor's designs and acknowledges that the contractor's work is complete and meets the requirements of the contract. The design certification review verifies the contractor's crew transportation system's capability to safely approach, dock, mate, and depart from the ISS, among other requirements. After the contractor has successfully completed all of its flight tests, as well as various other activities, the certification review determines whether the crew transportation system meets the Commercial Crew Program's requirements. The contractors must complete both acceptance events to receive NASA certification.

NASA and the contractors also identified discrete performance-based events, called interim milestones, which occur as the contractors progress toward the two acceptance events. Each interim milestone has pre-determined entrance and exit criteria that establish the work that must be completed in order for the contractor to receive payment. The interim milestones serve several functions, allowing the government to finance work from development to completion, review the contractors' progress, and provide approval to proceed with key demonstrations and tests. The

[7]An indefinite-delivery, indefinite-quantity contract may be used to acquire supplies or services during a specified contract period when the exact times and exact quantities of future deliveries are not known at the time of contract award.

program also uses these milestones to inform its annual budget request. Since the contracts were awarded, the Commercial Crew Program and the contractors have agreed to split several of the interim milestones. The contractors have also added new milestones, in part to capture changes in their development plans.

NASA has also made changes to the contracts that have increased their value. While the contracts are fixed-price, their values can increase if NASA adds to the scope of the work or otherwise changes requirements. As of July 2017, NASA had increased the value of contract line item 001 for Boeing by approximately $48 million for hardware and software requirement changes, and contract line item 001 for SpaceX by approximately $91 million for a hardware requirement change and the addition of cargo during an ISS test flight.

In our February 2017 report,[8] we found the following:

- Both of the Commercial Crew Program's contractors have made progress developing their crew transportation systems, but both also have aggressive development schedules that are increasingly under pressure. Both Boeing and SpaceX had determined that they would not be able to meet their original 2017 certification dates, and both expected certification to be delayed until 2018. We found that the schedule pressures were amplified by NASA's need to provide a viable crew transportation option to the ISS before its current contract with Russia's space agency runs out in 2019. If NASA needs to purchase additional seats from Russia, the contracting process typically takes 3 years. Without a viable contingency option for ensuring uninterrupted access to the ISS in the event of further Commercial Crew delays, we found that NASA was at risk of not being able to maximize the return on its multibillion dollar investment in the space station.
- The Commercial Crew Program was using mechanisms laid out in its contracts to gain a high level of visibility into the contractors' crew transportation systems, but maintaining the current level of visibility through certification could add schedule pressures. For example, due to NASA's acquisition strategy for this program, its personnel are less involved in the testing, launching, and operation of the crew transportation system. And while the program has developed

[8]GAO-17-137.

productive working relationships with both contractors, the level of visibility that the program had required thus far had also taken more time than the program or contractors anticipated. Ultimately, the program has the responsibility for ensuring the safety of U.S. astronauts, and its contracts give it deference to determine the level of visibility required to do so. Moving forward though, we found that the program office could face difficult choices about how to maintain the level of visibility it feels it needs without adding to the program's schedule pressures.

In order to ensure that the United States had continued access to the ISS if the Commercial Crew Program's contractors experienced additional schedule delays, we recommended that the NASA Administrator develop a contingency plan for maintaining a presence on the ISS beyond 2018, including options to purchase additional Russian Soyuz seats, and report to Congress on the results. NASA concurred with this recommendation, and in February 2017, NASA executed a contract modification to procure an option for three crewmember seats from Boeing on the Russian Soyuz vehicle. Our analysis found that these seats represented a contingency plan for U.S. access to the ISS through 2019. In April 2017, NASA informed the Congress of this action.

Both Contractors Have Made Progress but Continue to Experience Schedule Delays

Contractors Continue to Advance Development of Their Crew Transportation Systems

Both Boeing and SpaceX have continued to make progress finalizing their designs and building hardware as they work toward final certification of their crew transportation systems, since we last reported in February 2017.[9] Each contractor's system includes a spacecraft and a launch vehicle with supporting ground systems. The contractors are also manufacturing test articles and flight spacecraft to support the uncrewed and crewed flight tests. The contractors plan to use the test articles to

[9]GAO-17-137.

demonstrate system performance and the flight spacecraft to demonstrate their ability to meet contract requirements.

As table 1 shows, these test articles and flight spacecraft are currently in varying stages of completion—some are completed and in testing while others are still early in the manufacturing phase. Should any issues arise during integration and test or the flight tests planned for 2018, the contractors may have to complete rework on the spacecraft already under construction.

Table 1: Description of Boeing and SpaceX Hardware, Current Status, and Upcoming Events as of Fourth Quarter Calendar Year 2017

Spacecraft (name and type)	Purpose	Current status	Upcoming events
Boeing			
Flight spacecraft 1	Environmental testing 2018 Quarter (Q) 4 crewed flight test 2019 Q3 second post-certification mission	Crew module: constructed and integrated Service module: in construction	Boeing plans to conduct environmental testing starting in spring 2018 to test the spacecraft in conditions that simulate the space environment.
Flight spacecraft 2	2018 Q3 uncrewed flight test 2019 Q2 first post-certification mission	Crew module: in construction Service module: in construction	Boeing plans to join the crew and service modules together in the first quarter of 2018.
Test article 1	Validate effectiveness of spacecraft design and abort system	Crew module: constructed and integrated Service module: constructed and integrated	This test article has undergone testing throughout 2017.
Test article 2	Support ground tests 2018 Q2 pad abort test	Crew module: constructed and integrated Service module: in construction	This test article is completing testing before it will be reconfigured to support the pad abort test.

Spacecraft (name and type)	Purpose	Current status	Upcoming events
SpaceX			
Flight spacecraft 1	2018 Q3 uncrewed flight test	Crew module: constructed and integrated Support module:[a] in construction	SpaceX plans to join the crew and support modules together in the second quarter of 2018.
Flight spacecraft 2	2018 Q4 crewed flight test	Crew module: in construction Support module: in construction	SpaceX plans to join the crew and support modules together in the third quarter of 2018.
Flight spacecraft 3	2019 Q2 first post-certification mission	Crew module: in construction Support module: not yet started	SpaceX plans to join the crew and support modules together in the first quarter of 2019.
Test article	Support spacecraft propulsion testing	Testing is underway to validate performance of spacecraft engine propulsion system.	SpaceX plans to complete this testing by the third quarter of 2018.

Source: GAO analysis of National Aeronautics and Space Administration and contractor documents. | GAO-18-317T

[a]For the purposes of this report, we refer to the SpaceX's Dragon as the crew module— it is composed of a pressure section and a service section. We refer to SpaceX's trunk as the support module. According to SpaceX, it serves as the launch vehicle adapter, it includes solar arrays for on-orbit power, and guidance fins for escape abort scenarios.

Schedule Delays Continue, and Risks Remain to Final Certification Dates

The contractors have notified NASA that final certification dates have slipped to the first quarter of calendar year 2019 and, through our ongoing work, we have identified three key risk areas that could further delay certification of each contractor's crew transportation system. These areas are (1) the contractors' aggressive schedules, (2) programmatic and safety risks, and (3) Commercial Crew Program's workload. These are consistent with the challenges we found facing the contractors and program in our February 2017 report.[10]

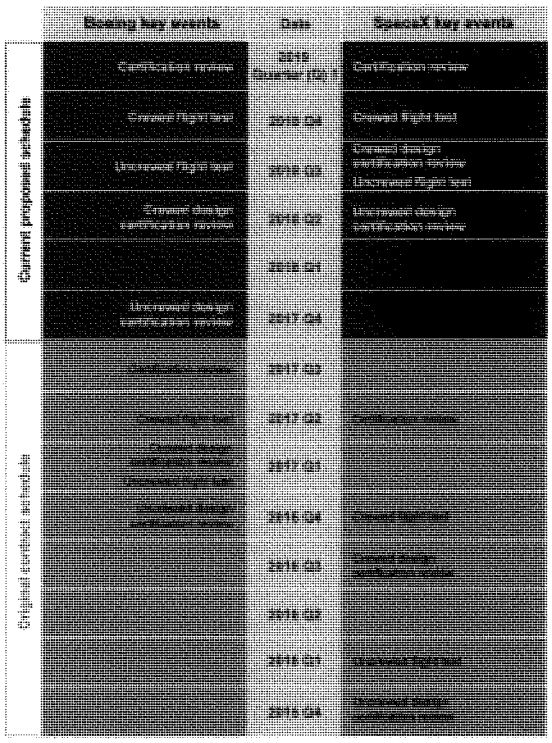
Aggressive schedules. Since the award of the current Commercial Crew contracts in September 2014, the program, Boeing, and SpaceX have all identified the contractors' delivery schedules as aggressive. Program officials told us that, from the outset, they knew delays were likely due to the developmental nature of the program. Multiple independent review bodies—including the program's standing review board, the Aerospace

[10]GAO-17-137.

Safety Advisory Panel, and the NASA Advisory Council-Human Exploration and Operations committee—also noted the aggressiveness of the contractors' schedules as they move toward certification.

In February 2017, we found that both contractors had notified NASA that they would not be able to meet the 2017 final certification dates originally established in their contracts and expected final certification to be delayed until 2018. Based on our ongoing work, we found that the contractors have notified NASA that these dates have slipped further to the first quarter of calendar year 2019. Figure 2 shows the original Boeing and SpaceX contract schedule and the current proposed schedule for each contractor.

Figure 2: Boeing and SpaceX's Proposed Commercial Crew Schedule Delays as of Fourth Quarter Calendar Year 2017



Source: GAO analysis of National Aeronautics and Space Administrations contracts and documents. | GAO-18-317T

However, the extent to which these schedules represent an accurate estimate of each contractor's final certification date is unclear for the following two reasons:

1. Each contractor provides schedule updates to the Commercial Crew Program at quarterly status reviews, and the dates frequently change. The program has held 12 quarterly reviews since each contract was awarded. Boeing has reported a delay six times and SpaceX has reported a delay nine times that included at least one key event identified in the timeline above at these quarterly reviews.
2. The Commercial Crew Program is tracking risks that both contractors could experience additional schedule delays and, based on our ongoing work, we found that the program's own analysis indicates that certification is likely to slip into December 2019 for SpaceX and February 2020 for Boeing. Each month, the program updates its schedule risk analysis, based on the contractors' internal schedules as well as the program's perspectives and insight into specific technical risks. The Commercial Crew Program manager stated that differences between the contractors' proposed schedules and the program's schedule risk analysis include the following:
   - The contractors are aggressive and use their schedule dates to motivate their teams, while NASA adds additional schedule margin for testing.
   - Both contractors assume an efficiency factor in getting to the crewed flight test that NASA does not factor into its analysis.

   The program manager explained further that the program meets with each contractor monthly to discuss schedules and everyone agrees to the relationships between events in the schedule even if they disagree on the length of time required to complete events. The program manager added, however, that she relies on her prior experience for a better sense of schedule timeframes as opposed to relying on the contractors' schedules.

While NASA has a fixed-price contract with both SpaceX and Boeing, there are consequences to the delays to date and the lack of certainty surrounding the final certification date. The United States has spent tens of billions of dollars to develop, assemble, and operate the ISS over the past two decades, and NASA relies on uninterrupted crew access to help maintain and operate the station itself and conduct the research required to enable human exploration in deep space and eventually Mars, among other science and research goals. To ensure uninterrupted access to the

ISS through 2019, which includes launch and return of the astronauts, NASA purchased five seats on the Soyuz spacecraft through Boeing for an undisclosed value.[11] Boeing obtained these seats though a legal settlement with the Russian firm, RSC Energia, which manufactures the Soyuz. The NASA Office of Inspector General found in its annual report on NASA's top management and performance challenges that if the Commercial Crew Program experiences additional delays, NASA may need to buy additional seats from Russia to ensure a continued U.S. presence on the ISS.[12] Further, the ISS is planned to be operational through 2024. Unless there is a decision to extend the ISS's operational life, additional delays by Boeing and SpaceX may lessen NASA's return on investment with the contractors. We will continue to monitor this as part of our ongoing work.

Programmatic and safety risks. In addition to challenges facing Boeing and SpaceX's aggressive schedules, both contractors face other risks that will need to be addressed to support their certification. This includes the contractors' ability to meet the agency's requirements related to the safety of their systems. These risks are not unusual; there are inherent technical, design, and integration risks in all NASA's major acquisitions, as these projects are highly complex and specialized and often push the state of the art in space technology. The Commercial Crew Program monitors risks through two lenses—programmatic risks potentially affect the program's cost and schedule or the performance of the crew transportation system, and safety risks could elevate the potential for the loss of crew.

SpaceX Risks

Similar to our findings in February 2017, our ongoing work indicates that the Commercial Crew Program's top programmatic and safety risks for SpaceX, are in part, related to ongoing launch vehicle design and development efforts.[13]

SpaceX must close several of the program's top risks related to its upgraded launch vehicle design, the Falcon 9 Block 5, before it can be

[11]In 2015, NASA paid approximately $82 million per seat through its contract with the Russian Federal Space Agency (Roscocosmos). See GAO-17-137.

[12]National Aeronautics and Space Administration, Office of Inspector General, *NASA's 2017 Top Management and Performance Challenges*, November 2017 (Washington, D.C.: November 2017).

[13]GAO-17-137.

certified for human spaceflight. Included in this Block 5 design is SpaceX's redesign of the composite overwrap pressure vessel. SpaceX officials stated the new design aims to eliminate risks identified in the older design, which was involved in an anomaly that caused a mishap in September 2016. Separately, SpaceX officials told us that the Block 5 design also includes design changes to address cracks in the turbine of its engine identified during development testing.

NASA program officials told us that they had informed SpaceX that the cracks were an unacceptable risk for human spaceflight. SpaceX officials told us that they have made design changes, captured in this Block 5 upgrade, that did not result in any cracking during initial life testing. However, this risk will not be closed until SpaceX successfully completes qualification testing in accordance with NASA's standards without any cracks. SpaceX officials stated they expect this testing to be completed in first quarter calendar year 2018.

Finally, both the program and a NASA advisory group consider SpaceX's plan to fuel the launch vehicle after the astronauts are on board the spacecraft to be a potential safety risk. SpaceX's perspective is that this operation may be a lower risk to the crew. To better understand the propellant loading procedures, the program and SpaceX agreed to demonstrate the loading process five times from the launch site in the final crew configuration prior to the crewed flight test.

Boeing Risks

Our ongoing work indicates that Boeing is mitigating several risks in order to certify its crew transportation system, including challenges related to its abort system performance, parachutes, and its launch vehicle.

Boeing is addressing a risk that its abort system, which it needs for human spaceflight certification, may not meet the program's requirement to have sufficient control of the vehicle through an abort. In some abort scenarios, Boeing has found that the spacecraft may tumble and that could pose a threat to the crew's safety. To validate the effectiveness of its abort system, Boeing has conducted extensive wind tunnel testing and plans to complete a pad abort test in April 2018.

Boeing is also addressing a risk that during re-entry to the Earth's atmosphere, a portion of the spacecraft's forward heat shield may reconnect and damage the parachute system.[14] NASA's independent

[14]The forward heat shield protects the parachute system during re-entry.

analysis indicates that this may occur if both parachutes that pull the forward heat shield away from the spacecraft deploy as expected. Boeing's analysis indicates the risk exists only if one of two parachutes does not deploy as expected. If the program determines this risk is unacceptable, Boeing would need to redesign the parachute system, which the program estimates could result in at least a 6-month delay. Finally, one of the program's top programmatic and safety concerns is that it may not have enough information from Boeing's launch vehicle provider, United Launch Alliance, to assess if the launch vehicle prevents or controls cracking that could lead to catastrophic failures. The program and Boeing are in the process of negotiating next steps.

Program Safety Risk

The Commercial Crew Program has identified the ability of it and its contractors to meet a crew safety requirement as one of its top risks. NASA established the "loss of crew" metric as a way to measure the safety of a crew transportation system. The metric captures the probability of death or permanent disability to one or more crew members. Under each contract, the current loss of crew requirement is 1 in 270, meaning that the contractors' systems must carry no more than a 1 in 270 probability of incurring loss of crew. Near the end of the Space Shuttle program, the probability of loss of crew was approximately 1 in 90. As part of our ongoing work, we continue to work with NASA to understand how the loss of crew requirement was established for the Commercial Crew Program.

Program officials told us that Commercial Crew is the first NASA program that the agency will evaluate against a probabilistic loss of crew requirement. They said that if the contractors cannot meet the loss of crew requirement at 1 in 270, NASA could still certify their systems by employing operational mitigations. They said this would entail a potentially increased level of risk or uncertainty related to the level of risk for the crew.

Program officials told us their main focus is to work with the contractors to ensure that the spacecraft designs are robust from a safety perspective. The loss of crew metric and the associated models used to measure it are tools that help achieve that goal. For example, Boeing told us that in early 2016, it needed to identify ways to reduce the mass of its spacecraft. As Boeing found opportunities to reduce the spacecraft mass, the program stated that it had to consider how implementing those design changes would affect its loss of crew analysis in addition to compliance with other performance and safety requirements. According to the program, it is working with both contractors to address the factors that drive loss of

crew risk through design changes or additional testing to gain more information on the performance and reliability of systems. As part of our ongoing work, we will continue to assess the extent to which the contractors are meeting this requirement and what tools the program and NASA will use to determine if the contractors meet the requirement.

Program office workload. In February 2017, we found that the Commercial Crew Program was using contractually defined mechanisms to gain a high level of visibility into the contractors' crew transportation systems, but also found that the Commercial Crew Program's workload was an emerging schedule risk.[15] At that time, program officials told us that one of their greatest upcoming challenges will be to keep pace with the contractors' schedules so that the program does not delay certification. Specifically, they told us they are concerned about an upcoming "bow wave" of work because the program must complete two oversight activities—phased safety reviews and verification closure notices—concurrently in order to support the contractors' design certification reviews, uncrewed and crewed flight test missions, and final certification.

The Commercial Crew Program is working to complete its three-phased safety review, which will ensure that the contractors have identified all safety-critical hazards and implemented associated controls, but it is behind schedule. Both the contractors and the program have contributed to these delays.

- In phase one, Boeing and SpaceX identified risks in their designs and developed reports on potential hazards, the controls they put in place to mitigate them, and explanations for how the controls will mitigate the hazards.
- In phase two, which is ongoing, the program reviews and approves the contractors' hazard reports, and develops strategies to verify and validate that the controls are effective.
- In phase three, the contractors plan to conduct the verification activities and incrementally close the reports.

The Commercial Crew Program's review and approval of the contractors' hazard reports have taken longer than planned. The program originally planned to complete phase two in early 2016, but through our ongoing

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work, we have found that as of October 2017, neither contractor had completed this phase. At that time, Boeing had completed 90 percent and SpaceX had completed 70 percent of the Phase 2 reports.

The Commercial Crew Program's verification closure notice process, which is used to verify that the contractors have met all requirements, is one of the other key oversight activities and potential workload challenges for the program. The program is completing that process concurrently with the phased safety reviews. The verification closure process is initiated by the contractor when it provides the program with data and evidence to substantiate that it has met each requirement, and is completed when the program has reviewed and approved the contractor's evidence to verify that each requirement has been met. The Commercial Crew Program must also approve a subset of verification closure notices before key tests or milestones can occur. For example, the ISS requirements and a portion of the Commercial Crew Program requirements must be met before Boeing and SpaceX's uncrewed flights to the ISS, which are currently planned for the third quarter of 2018. The program's ability to smooth its workload is limited because the contractors generally control their development schedules. In February 2017, we found, however, that proposed changes to the Boeing and SpaceX schedules could help alleviate some of the concurrency between the program's phased safety reviews and verification closure process.[16] We will continue to monitor the efforts as part of our ongoing work.

In conclusion, Boeing and SpaceX continue to make progress developing crew transportation systems to help the United States re-establish its domestic ability to provide crew access to the ISS. But, when the current phase of the Commercial Crew Program began, there was widespread acknowledgment that the contractors' development and certification schedules were aggressive and the anticipated schedule risks have now materialized. Further, programmatic and safety risks remain with schedules that frequently change making a final certification date uncertain. Delays and uncertain final certification dates raise questions about whether the United States will have uninterrupted access to the International Space Station beyond 2019, and may lessen NASA's return on investment with the contractors. We look forward to continuing to work

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with NASA and this subcommittee as we assess the contractors' and program's progress to final certification.

Chairman Babin, Ranking Member Bera, and Members of the Subcommittee, this completes my prepared statement. I would be pleased to respond to any questions that you may have at this time.

GAO Contact and Staff Acknowledgments

If you or your staff have any questions about this testimony, please contact Cristina T. Chaplain, Director, Acquisition and Sourcing Management at (202) 512-4841 or chaplainc@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this statement. GAO staff who made key contributions to this statement include Molly Traci, Assistant Director; Susan Ditto; Lisa Fisher; Laura Greifner; Juli Steinhouse; Roxanna Sun; and Kristin Van Wychen.

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Strategic Planning and External Liaison	James-Christian Blockwood, Managing Director, spel@gao.gov, (202) 512-4707 U.S. Government Accountability Office, 441 G Street NW, Room 7814, Washington, DC 20548

Cristina T. Chaplain

Ms. Chaplain currently serves as a Director, Acquisition and Sourcing Management, at the U.S. Government Accountability Office. She has responsibility for GAO assessments of military space acquisitions, NASA, and the Missile Defense Agency. Among other topics, she has led reviews on the International Space Station, the Space Launch System and the Orion crew capsule, acquisition progress for major NASA projects, the James Webb telescope, commercial cargo and crew, NASA contract management, contract terminations, weather satellites, and the Global Positioning System. In addition to her work on space and missile system development, Ms. Chaplain has led a variety of DOD-wide contracting-related and best practice evaluations for the GAO. Before her current position, Ms. Chaplain worked with GAO's financial management and information technology teams. Ms. Chaplain has been with the GAO for 26 years. She received a bachelor's degree, magna cum laude, in International Relations from Boston University and a Masters Degree in Journalism from Columbia University.

Chairman BABIN. Thank you, Ms. Chaplain. We appreciate it. I'd like to now recognize Dr. Sanders for five minutes to present her testimony.

TESTIMONY OF DR. PATRICIA SANDERS,
CHAIR, NASA AEROSPACE SAFETY ADVISORY PANEL

Dr. SANDERS. Chairman Babin, Ranking Member Bera, Mr. Smith, and Members of the Subcommittee, thank you for the opportunity to appear before you today to discuss the status of NASA's Commercial Crew Program.

The Aerospace Safety Advisory Panel believes that NASA's Commercial Crew Program is at a critical juncture, well beyond paper design with hardware being produced, testing underway, and first flights, uncrewed demo flights followed by crewed demo flights, on the horizon. This is a time when it is important to retain focus on program details while not giving in to schedule pressure; to maintain schedule awareness but to continue with program plans without neglecting, shortchanging, or deleting planned content. We continue to strongly caution that any wavering in commitment negatively impacts cost, schedule, performance, workforce morale, process discipline, and most importantly, safety.

We see continual steady progress toward providing the capability for crew transportation to low-Earth orbit and the International Space Station with both providers currently planning for flight tests later this year.

We also know that based on the quantity, significance, and associated uncertainty of work remaining for both commercial providers, the panel believes that there is a very real possibility of future schedule slips. There are several major qualification and flight test events that historically are schedule drivers or could reveal the need for additional work. These are things such as pyro shock qualification tests, parachute tests, engine hot fires, and qualification runs, abort tests, and both the crewed and uncrewed demos.

In addition to the technically complex test and qualification work remaining for the providers, NASA also has, as Cristina pointed out, a significant volume of work remaining itself. 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 as well as the majority of certification requirements verifications. It's not unusual for that to come at this point in time in the program, but that is remaining to be done.

Despite the volume of remaining work, the technical challenges and the upcoming end of the Soyuz transportation for U.S. crews, the panel sees no evidence that the program leadership is making decisions that prioritize schedule over safety risk, over crew safety. We expect to see several significant certification issues brought to culmination in the next year that will require NASA careful consideration and risk acceptance decisions at a very high level within the agency. It is possible that in some cases, the most beneficial and balanced options for the mission will require a decision to accept a higher risk. 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 the International Space Station. This requires one provider be certified

and ready to fly crew to the station by mid- to late 2019. Certification of the second provider could happen after that time.

The panel believes that NASA is addressing safety properly, but space can be a decidedly hostile environment, and human spaceflight is inherently risky. There's no excuse for negligence in the safety arena, but it is impossible to eliminate or control every potential hazard.

With the Commercial Crew Program, NASA has introduced an approach to developing spaceflight assets in cooperation with commercial providers. The future brings potential for more partnerships, bringing more opportunities and challenges with respect to safety processes and mechanisms.

In the coming year, the panel plans to spend focused effort on commercial crew and also look to the future of responsible and exciting human space exploration.

And I look forward to your questions.

[The prepared statement of Dr. Sanders follows:]

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January 17, 2018

Statement of
Dr. Patricia Sanders
Chair
National Aeronautics and Space Administration's
Aerospace Safety Advisory Panel

before the

Subcommittee on Space
Committee on Science, Space and Technology
U. S. House of Representatives

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to appear before you today to discuss the status of NASA's Commercial Crew Program (CCP).

The Aerospace Safety Advisory Panel believes 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 Panel has consistently articulated 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.

With respect to the Commercial Crew Program specifically, we see continual steady progress toward providing the capability for crew transportation to low-Earth orbit and the International Space Station (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.

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 flight tests. Also, SpaceX is still working on 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. I will discuss this issue, which has significant work ahead, later.

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 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 these Notices 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.

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 Program 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 Panel 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.

I will now address the Commercial Crew Program's Probabilistic Risk Assessment (PRA) requirement for loss of crew (LOC) which, covering a 210-day mission to ISS, is 1 in 270. In clarifying the requirement, the Program 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).

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:

- Micrometeoroid and Orbital Debris (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.

I will return now to the Falcon 9 helium tank redesign and qualification. At this time last year, 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, a Panel 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 liquid oxygen (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 annual 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.

In closing, let me say that 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 eliminate or control every potential hazard.

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.

With the Commercial Crew Program, NASA has introduced an approach to developing space flight assets in cooperation with commercial providers. The future brings the potential for more partnerships bringing both opportunities and challenges with respect to safety processes and mechanisms. In the coming year, the Panel plans to spend focused effort on Commercial Crew and also look to the future of responsible and exciting human space exploration.

Dr. Patricia Sanders

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

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

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

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

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

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

Chairman BABIN. Thank you very much for your testimony, Dr. Sanders.

I'd like to introduce a young lady that's from my district because she's from Texas A&M as an intern from Dayton, Texas, in District 36, Ashton Stevenson. Raise your hand or stand up, Ashton. Thank you. Good to have you here this morning.

I want to thank the witnesses for their testimony, and now I'd like to recognize myself for five minutes for questions.

Recent press reports indicated that a U.S. Government mission named Zuma may have either failed in orbit or the launch could have been unsuccessful. I do not want to discuss anything classified in an open session. The circumstances surrounding this mission do have a direct impact on NASA and this Committee's jurisdiction and oversight responsibilities. For instance, the launch vehicle used for the mission was developed with substantial NASA funding. The rocket is also scheduled to launch the Transiting Exoplanet Survey Satellite (TESS) mission in March. More importantly, the rocket will be used in the Commercial Crew Program that we are discussing today. Knowing the operational history of the system that NASA will put people on is an issue of life and death, literally. Similarly, the Zuma spacecraft was reportedly built by Northrop Grumman who is building a $9 million James Webb Space Telescope for NASA.

Understanding Northrop Grumman's work is clearly important to NASA and the Committee. So I'd like to address the first question to you, Dr. Koenigsmann. Thank you for committing to provide an unclassified briefing on the Zuma mission. If the Committee needs more information, will SpaceX provide this Committee with a briefing on this mission in a classified setting?

Dr. KOENIGSMANN. Thank you for your question. I want to point out on the Zuma mission that we relayed the information that Falcon 9 performed as specified, and it actually performed very well as specified and that we are picking up the launches by the end of the month as we planned all the time.

Regarding the briefing, we will go through the proper channels and follow the protocol. As you pointed out, we can't talk any details in this particular setting.

Chairman BABIN. Okay. Thank you. And to Mr. Gerstenmaier, does anyone at NASA know the details of the Zuma mission?

Mr. GERSTENMAIER. We do not know the details of the mission per se, but we've been informed by others that if there's any mishap investigation or any other activities that are involved, we will be appropriately involved in that activity.

Chairman BABIN. Okay. Well, why would NASA place astronauts on systems without knowing the systems' full operational heritage? And it brings to mind President Reagan's use of the Russian proverb, trust but verify.

Mr. GERSTENMAIER. Again, we will know if this is declared a mishap and we understand that if it's a mishap, NASA will be informed and we will have appropriate personnel participate in those mishap activities.

Chairman BABIN. Okay. Thank you. Following the explosion of the SpaceX rocket and the Amos 6 spacecraft on the launch pad, SpaceX was not able to determine a single most-probable cause of

the event, instead identifying several credible causes related to the composite overwrap pressure vessel, or COPV, helium tank. SpaceX modified its operations to prevent similar events going forward but still doesn't know the exact cause. The ASAP report states the panel considers this to be the most critical step in clearing the COPV for human spaceflight 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. The report goes on to state, in our opinion, adequate understanding of the COPV behavior and cryogenic oxygen is an absolute essential precursor to potential certification for human spaceflight.

Dr. Sanders, how many launches with a stable configuration should NASA require SpaceX and Boeing to achieve before certification?

Dr. SANDERS. That's a very difficult question. Thank you. Right now I believe NASA is planning to require seven launches with that configuration, and we believe that's an appropriate number.

There's some statistical evidence that Mr. Gerstenmaier could probably talk to a little bit better than I can on why that is a reasonable number. It is not a totally random number. It is a number that's predicated on having more than a few but having a timeframe in which you can actually accomplish those and still get on with certification and make the right risk decision on flying.

Chairman BABIN. Okay. Thank you very much. And Mr. Gerstenmaier, will NASA certify SpaceX to carry NASA astronauts without knowing the root cause of the Amos 9 failure? And will NASA allow SpaceX to use the load-and-go procedure for either commercial crew or the uncrewed missions?

Mr. GERSTENMAIER. We may not ever know the exact root cause of the failure that was associated with Amos, but we have a very intensive test program in cooperation with SpaceX and NASA doing some testing to identify the contributing causes or potential causes of that failure.

SpaceX is doing a redesign of the composite overwrap pressure vessel system, and Hans can talk to you about the details of that. We're participating in that. We will do the testing. We will understand the most likely contributors, and we will remove those from the failure chain and make sure that we're really ready and safe to go fly and the system is ready for crew before we put them on board.

In terms of the so-called load and go, we're in the process of looking at the best time to put the crew on the vehicle. We'll take into account the hazards associated with the specific vehicle designs, how much propellant is being actively loaded, what systems are operating, what hazards are associated with those activities, and we will find the appropriate time, along with the contractors, to put crew on this particular vehicle design that is most appropriate for the lowest risk to our crews and overall lowest risk to the—or gives us the highest probability of mission success. And we're in the process of working with both providers to determine the appropriate time to put crew on the vehicles.

Chairman BABIN. Excellent. Thank you very much. My time is expired, so I'd like to go to the gentleman from California, Mr. Bera.

Mr. BERA. Thank you, Mr. Chairman. Mr. Gerstenmaier, in your opening testimony you talked about how NASA is aware of the schedule but not driven by the schedule. I think those were the terms that you used. And Ms. Chaplain, I believe I heard you correctly that while NASA's engineers are involved working with both Boeing and SpaceX, it's mostly internal at Boeing and SpaceX, that NASA's engineers aren't intimately involved in the design and manufacturing. Did I hear that correctly?

Ms. CHAPLAIN. Yes, not as involved as they would be in a typical program such as like an Orion spacecraft.

Mr. BERA. Okay. And again, this is evolution of—you know, if I think about the early days of Apollo where NASA was the launch vehicle, NASA was the commercial crew vehicle, was the lunar landing vehicle, was the science vehicle, I mean, it's not a bad thing to see evolution and progress. Fifty years ago we would not have imagined U.S. astronauts going up to a space station on a Russian vehicle, but yet, that's where we find ourselves today.

I guess for Mr. Gerstenmaier, what is the—how intimately are NASA engineers involved as we start to go back into space?

Mr. GERSTENMAIER. We again look back at kind of our history and experience in spacecraft design, development, and safe operations. And there's certain areas that we deemed as higher risk across the systems. We also look at the specific designs where problems have occurred and that we've seen in other testing, and then we involve ourselves very heavily in those areas.

So for example, we talked about the composite overwrap pressure vessel activity, we have our own test facility at White Sands at which we're working with SpaceX to go do a kind of independent test to verify and validate that that's there. So we take these selected areas. We don't do it across the board with every design element, but the ones that we think have the highest risk or have the highest potential to be a safety impact, we're heavily involved in those areas and we're working hand in hand with both contractors.

Another area is parachutes. We're very heavily involved in the parachute design activities, certification activity. We're using our experience we've had with the Orion spacecraft. We're providing that to both Boeing and SpaceX. They can use that in their designs, and we have our engineers participating with them in those activities.

So we selectively pick the areas that we think are highest risk and we delve into the area that we need. If we see something we don't like, we can ask the contractor to do extra work for us or we can do testing ourselves.

Mr. BERA. Okay. And that level of cooperation, you know, coming from NASA, I guess to both of the contractors, Mr. Mulholland and Dr. Koenigsmann, you're also reaching out to NASA knowing that they have critical expertise and obviously a lot of knowledge from years of sending people, you know, crews?

Mr. MULHOLLAND. Yeah, absolutely. I think NASA has added a lot of value to the process. From the very beginning, we thought it would be advantageous for us to embed NASA within our team. So we've got NASA personnel in our factory every day with us. We have weekly review meetings across all the technical teams.

They're in our engineering review board. They provided a lot of value, and we are dedicated to doing this transparently.

Mr. BERA. And the same with SpaceX?

Dr. KOENIGSMANN. And yes. It's a very similar situation for us, too. We have NASA personnel on site. At every workday we include them in important meetings and some of the risk boards and on some other boards. We have a very close relationship with NASA, and we actually share hardware and test plans regarding some of the tests we'd be performing here.

Mr. BERA. Okay.

Dr. KOENIGSMANN. So it's a—in my opinion, it's more hand in hand——

Mr. BERA. It's a partnership.

Dr. KOENIGSMANN. —cooperation and it's not we do the work and, you know—it's just a much closer relationship than I envisioned.

Mr. BERA. And in our conversation yesterday, right now the contract between NASA and the contractors are for single-use vehicles. So, you know, for the Dragon vehicle, it would be a new one each time you take a crew up. And is it the same for Starliner as well, that these would be single use in the current contract?

Mr. MULHOLLAND. From a Starliner perspective, we have a two-piece spacecraft. We have an expendable service module that provides the propulsion for orbit, on-orbit adjustments, the de-orbit burn, and also abort if we had to. There's a new one every flight. The benefit that our system has is we land on land, a combination of parachutes and airbags. That allows reusability. So we will reuse the crew module up to 10 flights.

Mr. BERA. Mr. Gerstenmaier, currently though, is NASA contracting for the reuse of that crew vehicle or is it a new crew vehicle each time?

Mr. GERSTENMAIER. As Mr. Mulholland just explained, in the case of Boeing, the vehicle is reused——

Mr. BERA. Is reused.

Mr. GERSTENMAIER. —up to 10 times. In the case of SpaceX, we've asked for a new vehicle each time——

Mr. BERA. Each time.

Mr. GERSTENMAIER. —and we'll continue to review that with SpaceX.

Mr. BERA. Okay. And in the long-term planning, with the reuse of vehicles, is the expectation that will bring costs down over time?

Mr. GERSTENMAIER. Yes. We believe that it has the potential to bring down costs. We're also looking even at the Orion spacecraft for potential reuse of it in certain areas.

There's some advantage of using a reused vehicle in the fact that you've got a chance to actually see it in flight. You get to see its performance. As long as you're not taking life out of the system or it's not degrading the system, the fact that it's flown gives you some insight into the environment that it's going to operate and gives you some insight into operations that may actually be beneficial to you.

Mr. BERA. Is there an expectation potentially, if Dragon is being designed to be reused as well to think about Dragon as a reuse vehicle as well?

Mr. GERSTENMAIER. Maybe Hans might address that better than myself.

Dr. KOENIGSMANN. Yeah, Dragon is designed for usability, and we actually have been able to demonstrate that on the current cargo Dragon, particularly with the last launch we used a first stage and a cargo Dragon. So that was a major accomplishment in my opinion in terms of reusability.

And I do want to emphasize, too, that getting the vehicles back is an enormous opportunity to learn about the flight loads and what happened to it in-flight, not just by inspecting it but you can also add additional sensors that you then can download data from and don't have to rely just on the RF things.

So in our opinion, it's both a long-term cost savings and an incredible reliability advantage.

Mr. BERA. I've gone over my time, Mr. Chairman.

Chairman BABIN. Thank you very much. I'd like to now recognize the gentleman from Alabama, the Vice Chairman of our Subcommittee, Mr. Brooks.

Mr. BROOKS. Thank you, Mr. Chairman. I'm going to read from an article that was published earlier this week titled, "Doubts About SpaceX's Reliability Persists as Astronaut Missions Approach." It was in Forbes Magazine. The author is Loren Thompson, January 15, 2018, and then I'm going to ask some questions, in fairness, that we can have a response.

"In 2015, a Falcon 9 cargo mission to the International Space Station exploded minutes after launch, costing NASA $110 million. In 2016, an Israeli commercial satellite was destroyed on the ground when supposedly routine fueling procedures went dramatically awry. The launch pad was damaged by that explosion. In 2017 the latest version of the company's Merlin rocket engine blew up at a testing facility in Texas. And now SpaceX has begun 2018 with yet another catastrophe," referring to the billion dollar spy satellite that we recently lost. Resuming the quote, "Maybe SpaceX really isn't responsible for the latest failure; the problem might have been caused by a payload adapter that Northrop Grumman, the company that also built the lost satellite, supplied. But launch providers usually have final responsibility for tip-to-tail readiness before a rocket lifts off, and competitor ULA has successfully employed a variety of payload adapters to attach satellites to its rockets. The most worrisome aspect of this apparent pattern is that the same SpaceX launch vehicle will begin flight tests later this year to carry astronauts to the International Space Station." And I would add from another part of the article, "By way of comparison, United Launch Alliance, SpaceX's sole competitor in the military launch business, hasn't lost a single payload in 12 years and 124 missions."

Dr. Koenigsmann, you made a comment in your remarks in chief that SpaceX is achieving or attempting to achieve its goal of "safe, reliable, and affordable" launches. This record that is mentioned in the Forbes Magazine article, do you consider that to be consistent with a "safe and reliable and affordable" launch record?

Dr. KOENIGSMANN. Well, the record in this paper needs to be adjusted for accuracy, I think.

Mr. BROOKS. Please do. That's why I'm giving you the opportunity.

Dr. KOENIGSMANN. Thank you. Thank you very much for that. For one, the quoted test incident in Texas was not actually an engine explosion. There was a fire on the test stand when the engine wasn't even running and there was a test procedural error. It has nothing to do with the engine itself.

Regarding Zuma, we talked about this earlier. I can't unfortunately present any details. I can only reiterate that Falcon 9 did everything that Falcon 9 was supposed to do.

So on that record, the other two incidents are a while back, and we did learn our lessons on both of those, which is obviously not desirable. But at the end of the day, it's a thing we learned and we improved the vehicle based on what we saw during those incidents into a much safer vehicle. We took—in both cases we had investigations with government partners, NASA, FAA, the Air Force and so on and so forth. And we very openly discussed and presented our corrective action and acted on them, since then, which in my opinion, makes us a much better vehicle.

I do want to point out at the same time that Falcon 9 has actually characteristics that make it intrinsically safe. For example, it has nine engines on the first stage. You can lose an engine and make mission. You can actually lose two engines in some cases, not that we ever—not that I ever hope that that will happen, but obviously that is a tremendous guarantee. If you lose engines in other rockets and—you know, I want to point out, our engines are also domestically produced. Obviously this is much more difficult for other vehicles that have less engines. So that makes it safer.

I also pointed out reusability was already—is a great point to get the vehicles back and inspect them. That is something that we started doing I think it was December, not this last year but the year before. And ever since then have we had a chance to inspect the vehicles or to make sure that the actual——

Mr. BROOKS. Please, I have a follow-up question for Ms. Chaplain, and I gave you as much time as I could.

Dr. KOENIGSMANN. I'm sorry.

Mr. BROOKS. And I appreciate your correcting the article as you understood it with Loren Thompson where you agree with two, you contest one, and then the other still yet to be determined.

But Ms. Chaplain, how does the GAO evaluate SpaceX's record or goal of safe and reliable and affordable?

Ms. CHAPLAIN. Well, on the issue of safety and the accidents mentioned today, I would just remind people that DOD went through its own phase of having launch accidents right before their current program started, the evolved expendable launch vehicle. And once that started, they realized pretty quickly on that they had to add mission assurance. So they've had a lot of time in the past to learn from mistakes, to do the things that they need to do to get safety and mission assurance into the program.

In my view, I think some of that learning is still going on here for the providers because they're new vehicles, they're new to the government arena, and procedures, mission assurance, things like that are things they're going to be learning over time and they've already learned quite a bit.

Mr. BROOKS. Thank you for your insight and rebuttal of the article. I appreciate it.

Chairman BABIN. And I'd like to recognize the Ranking Member, Ms. Johnson, from Texas.

Ms. JOHNSON. Thank you very much. Excuse my voice. For I guess Gerst, the ASAP report discusses the accident investigation regarding the on-pad explosion of Falcon 9 rocket in 2016. And the report says that NASA conducted an independent review in addition to the standard accident review. Has that been distributed yet?

Mr. GERSTENMAIER. No, it's not, and it's in review now. We have a summary of that report in review with SpaceX, and as soon as we complete the discussions with them, we'll have that summary available for folks to take a look at.

Ms. JOHNSON. Okay. We look forward to reviewing that. For Dr. Sanders, it's my understanding that one of the commercial crew launch vehicles, the Falcon 9, has experienced several primary mission failures over the past four years and suffered a major engine anomaly in recent months, any of which occurrence would have forced a stand-down if it had happened to the space shuttle. In addition to other commercial crew launch vehicle, the Atlas V is powered by the Russian-built RD–180 engine for which detailed design data is still unavailable.

What will NASA need to do to ensure that either of the launch systems will be safe enough to fly astronauts on?

Dr. SANDERS. Thank you. NASA has a very rigorous certification program in place for both commercial crew providers. There are a very large number of verification notifications that have to be filed. There's evidence that has to be provided from the tests that say this is—they have met all these requirements.

I think that by the time they weed through all of that, NASA will be able to make a reasonable decision relative to residual risk. The problems that have experienced with Falcon 9 as Dr. Koenigsmann has just said have been addressed in the past but there is still work to be done, particularly on the composite overwrap pressure vehicle.

The RD–180 data or lack thereof for the launch vehicle for the Boeing variant I think has been resolved by finding an alternative way to get insight into that design.

Ms. JOHNSON. Thank you very much. Ms. Chaplain, would you like to comment on that?

Ms. CHAPLAIN. I think there's going to be some gaps as they come to the end, and they're going to have to make a risk-based decision on whether to go forward with some gaps in knowledge. I don't think you're going to get complete knowledge of the Atlas V. That program began as a commercial program, and there wasn't some data obtained that we've never been able to get. So at some point, NASA's just going to have to decide how much—is the insight they have enough? Is the track record enough? Is the data they've gotten alternatively enough? And they'll have to make their own risk-based choice.

Ms. JOHNSON. Thank you very much.

Chairman BABIN. Thank you. And now, the gentleman from Oklahoma, Mr. Lucas.

Mr. LUCAS. Thank you, Mr. Chairman. And clearly the committee is extremely sensitive about both safety and cost. I'd like to begin my discussion of course with the most important question, safety.

Mr. Gerstenmaier, since this is the first time NASA will be certifying a commercial, a crew system for human spaceflight, could you expand for a moment about the differences between what you're doing and will be doing in the way of commercial system, a certification, versus the certification process you would be going through for a NASA-developed system?

Mr. GERSTENMAIER. I think the simplest way to describe it is we have a shared mission assurance or safety responsibility with the partners where the partners have responsibility to show that the vehicle is safe on their own, to show that it can be used for the intended activities that ferry crew to and from space. But then NASA also ultimately has the certification responsibility when we put our crews on those vehicles. So then we do a detailed assessment along with what they've done. So there's some things we've delegated to them to do to be fully certified to say they're ready to go and there's aspects where we double-check, and we oversee all aspects of what they're doing. So even the areas that they say are certified, we've taken a look at them. We've determined they're appropriate to put our crew on board, whereas it's our own internal program, we would do all that work ourselves.

Mr. LUCAS. And to that end, let's talk for a moment about the cost issues. And I turn to our friends from Boeing and SpaceX. One of the primary reasons for the private sector partnering and developing new systems, of course, was the concept that providing astronaut access to the International Space Station, the development costs to be shared by the contractors. I think we've had testimony before this committee indicating perhaps somewhere in the 80, 90 percent range of the development funds so far have been provided by NASA. I guess the question I'd simply put to you, how much skin in the game do each of you actually have, your organizations? And whoever would prefer to touch that first.

Mr. MULHOLLAND. Congressman, thank you. I don't have specific data available for me today on the amount of investment. The investment from the Boeing Company has been significant, and we consider this a strong partnership and an endeavor that we're fully committed to.

Dr. KOENIGSMANN. I want to say we have all of the skin in the future for us is Crew Dragon and Falcon 9. But with respect to this particular number, I have to state this for the record I don't remember this particular number. I do remember the number for the previous Crew Dragon contract which was significantly higher percentage wise.

Mr. LUCAS. And clearly the reason I ask this question is the same reason the constituents inquire about this. Simply put, whoever is successful, you accomplish something that will have benefits to your enterprise for a generation or two. So it's a legitimate point back from our folks.

Expand for a moment also if you would about your dealings individually company-wise with NASA so far as you go through the certification process, if you've had any surprises.

Dr. KOENIGSMANN. Yeah. So I want to point out we have an excellent relationship with NASA. I mean, obviously you have to I guess get a working relationship on the working level and that takes a little bit of time until we established a process. But by now we know how to, you know, work, go through the certification process. And it's not that this is something that happens, you know, once we're all done. This is ongoing at this point in time and works in parallel with the hardware development.

I'm pretty confident that we will finish this on time and get the astronauts up there before we have to fly any Russian vehicles. And obviously the test flights are as planned later this year.

Mr. MULHOLLAND. Obviously, a very strong relationship with NASA. We've been a part of every human spaceflight program from the beginning. I think the proof of the relationship is in the product, and as of today, of the 800 verifications as we look forward to certification of the vehicle, of the 800-plus verifications that we have to complete and send over to NASA, over 200 have already been delivered. And of those, over 150 have already been approved.

The other big part of certification is the verification of hazard controls. We have 16,000 hazard control verifications that we have to present to NASA. Of those, over 11,000 have already been dispositioned and given to NASAS for review.

So to me, the proof is in the product and the partnership that we have and the disposition of those successfully speaks volumes.

Mr. LUCAS. Thank you. I yield back, Mr. Chairman.

Chairman BABIN. Yes, sir. Thank you, Mr. Lucas. The gentleman from Illinois, Mr. Foster.

Mr. FOSTER. Thank you, Mr. Chairman. One of the large cost drivers in any of this sort of project is the high level specification on the probability of loss of crew and an equally important number, the probability of loss of mission. You know, it's my understanding that it's 1 in 270 is viewed as an acceptable probability of loss of crew and you sort of design around that? Is that a correct understanding?

Mr. GERSTENMAIER. Yes.

Mr. FOSTER. Yeah. So one in—all right. And so what is the number then for an acceptable probability of loss of mission which is presumably allowed to be significantly higher and perhaps more of an economic tradeoff? Is there a design number for that as well?

Mr. GERSTENMAIER. The requirement for loss of mission is 1 in 55.

Mr. FOSTER. Okay. All right. So that's—now which of the Falcon 9 accidents that have been talked about would have resulted, had they been manned, would have resulted in a loss of crew as opposed to loss of mission?

Dr. KOENIGSMANN. Thank you very much for that question. Certainty the first incident that we had a mishap, the crew would have been safe with the launch escape system. There's no question about that because Dragon——

Mr. FOSTER. This is the——

Dr. KOENIGSMANN. This is this year.

Mr. FOSTER. —on-pad——

Dr. KOENIGSMANN. No, this is the one in flight.

Mr. FOSTER. —fuel. The one in flight?

Dr. KOENIGSMANN. Yeah. As we can see, Dragon's heat shield acts as a barrier there, and we can see Dragon separate in this particular case. In fact, we made changes on the Dragon software because if you would have deployed the parachute, you might have been able to save the capsule at that particular point. So that's—the launch escape system would have helped there, absolutely. The same is true for the pad abort system which we tested last year, two years ago actually.

Mr. FOSTER. Pad abort? This is the——

Dr. KOENIGSMANN. Right.

Mr. FOSTER. —pad explosion incident.

Dr. KOENIGSMANN. No, this is addressing an incident on the pad. In this case, it's——

Mr. FOSTER. How long did you have? I think I read somewhere 93 milliseconds from the first anomaly in the telemetry?

Dr. KOENIGSMANN. It's very short and——

Mr. FOSTER. And would that have been sufficient for the crew escape?

Dr. KOENIGSMANN. It competes with starting up the engine. So it's certainly a race condition there. But I personally believe that the heat shield and the structure on Dragon would have protected the astronauts sufficiently to let the engine start and go. But that's certainly something that you never, ever want to test.

Mr. FOSTER. Okay. But it is——

Dr. KOENIGSMANN. Yes.

Mr. FOSTER. —your estimate——

Dr. KOENIGSMANN. Yes.

Mr. FOSTER. —that that probably would have not?

Dr. KOENIGSMANN. No, I think my estimate is——

Mr. FOSTER. Resulted in loss——

Dr. KOENIGSMANN. —that this would have—yeah, exactly that. It would have saved the astronauts. That's my estimate. It's a little bit of guessing on my side obviously because that is something we don't want to, you know——

Mr. FOSTER. Okay. And this latest thing that cannot be fully talked about, the fact that there was at least—it had basically achieved orbit or very close to it?

Dr. KOENIGSMANN. Falcon 9 did what Falcon 9 was supposed to do and——

Mr. FOSTER. All right. And so presumably, you know, if a flaw had been detected in performance, there would have been contingency plans to rescue the crew?

Dr. KOENIGSMANN. There are——

Mr. FOSTER. And then so that——

Dr. KOENIGSMANN. There are always——

Mr. FOSTER. Is there any——

Dr. KOENIGSMANN. —plans to keep the crew safe and we have—well, as a point of knowledge, we have a late abort capability. We can actually abort when we are close to orbital velocity. And in this case, the abort would be not to land but to orbit. That's a really interesting feature I think on Crew Dragon that can always be useful.

Mr. FOSTER. And I guess the last question, the probability of loss of mission is a number that is at least in part an economic tradeoff.

And so I was wondering, is that something that gets negotiated upward when a project gets in trouble, that as long as you maintain the probability of the loss of crew——

Dr. KOENIGSMANN. Oh, no.

Mr. FOSTER. —that whether it's viewed as an acceptable practice to——

Dr. KOENIGSMANN. No.

Mr. FOSTER. —make an adjustment of that?

Dr. KOENIGSMANN. I don't think so. I mean, that would be—safety is our primary goal.

Mr. FOSTER. I'm talking about material. This is——

Dr. KOENIGSMANN. Absolutely.

Mr. FOSTER. —loss of mission. This is loss of the payload rather than loss of life. And is it viewed—you know, I would not be shocked or even necessarily unhappy to find that there was some more flexibility in the probability of loss of mission as a project, you know, gets into schedule trouble, for example.

Dr. KOENIGSMANN. Let me just say the—I'm not sure loss of mission actually is a problem right now. But in terms of the probability of loss of crew, one of the key drivers is actually the time on station when the capsule sits there more or less empty. There are ways to address this. And we have done—based on the probability risk assessment, we have done design changes to protect the hardware. And that's actually what this number is supposed to be for in my opinion. It's a number that can identify critical areas that you then change the design and add armor basically to protect it. That's the main usefulness of this type of analysis.

Mr. FOSTER. All right. Thank you and I guess I'm out of time and yield back.

Chairman BABIN. Thank you very much. Let's see. The gentleman from California, Mr. Rohrabacher.

Mr. ROHRABACHER. Thank you very much, Mr. Chairman. And let me just note that this is a very unique way of approaching achieving a goal that we're looking at today. And usually in the past we've seen either one contractor or the government itself trying to be the contractor to accomplish a mission. And what we have are two terrific companies, Boeing and SpaceX, which are providing us a new way of perhaps accomplishing our space goals. This is the first time that I know that we've actually had this type of competition.

Let me note that the Orion capsule is reused. Boeing has designed this to be reused. Is that correct?

Mr. MULHOLLAND. The Starliner capsule. Yes, sir.

Mr. ROHRABACHER. Okay. And on the other hand, SpaceX is trying to reuse their launch vehicle. So we have two different approaches, and I think this is what Congress wanted, some really—we have two different approaches, we're going to find out which one is the correct way. Maybe they're both good, but this is the type of innovation and an innovative approach. I do take it that we have saved money? Is that correct, Mr. Gerstenmaier?

Mr. GERSTENMAIER. Yes.

Mr. ROHRABACHER. So even with two companies and this new approach, we've saved money. However, let me note that the companies are operating under—have some real burden. And that is not

their burden but I understand that the budget that they've been operating on, that Congress has failed to fully fund this project that they have said they needed so much money. Is that correct, Mr. Gerstenmaier?

Mr. GERSTENMAIER. Initially, we had some startup problems with funding. But since those problems have been behind us, we've received the funding that we've requested each year for the Commercial Crew Program.

Mr. ROHRABACHER. Right. Yeah, I noted that when it was first started we got 64 percent of the funding and that was in 2011. 2012, 47 percent of the funding was requested was actually allocated. And then later on we had some, at least Congress being more responsible in trying to meet our responsibilities. So this program has saved money. We've got different approaches that are now being proven. And so it looks like the program is going along as we thought it would, even though there have been glitches. But there are glitches in the development of any new technology. Let me note that.

Ms. Chaplain, do you have confidence that this was the right approach for NASA to take?

Ms. CHAPLAIN. I think in taking this approach, NASA definitely learned some lessons from the past. There were early attempts to work with the commercial sector in a different way and to really have them drive the program and be partners with NASA. But they didn't succeed for things like not very good communication between the contractor and the government, maybe not as much insight as the government needed, not good risk mitigation planning. And in this case, NASA I believe took all those measures for commercial crew and the COTS program and even learned from the COTS program for commercial crew to avoid those past mistakes. So for a program like this that's trying to do business differently, they've instituted——

Mr. ROHRABACHER. So do you still have confidence that we should have taken this approach?

Ms. CHAPLAIN. It's a good approach for this endeavor. We don't like to endorse one or the other.

Mr. ROHRABACHER. Okay.

Ms. CHAPLAIN. But for this program of this nature, they're following a good approach and adopting good practices for managing it.

Mr. ROHRABACHER. All right. And how about Ms. Chaplain? I mean, Dr. Sanders, would you still have faith in this approach that Congress started years ago? And by the way, when you don't fund a program by what is guestimated for the need of the program, doesn't that also increase the risks that people take?

Dr. SANDERS. Yes, it does, and that can be a problem. I believe that this was an interesting, new way to do this. It was—it had came with challenges, and if I stick with safety, they learned some new things about managing risk and shared risk management that are probably good for the future. They had to learn some new things because it wasn't the way it was done in the past. I think by and large, it bodes well for the future.

Mr. ROHRABACHER. So do you still have faith——

Dr. SANDERS. I have——

Mr. ROHRABACHER. —in this approach? Well, thank you very much, and Mr. Chairman, let's just note that with this type of—as we move forward now developing this program, we still face major challenges for things like space debris and how, even if they do their job perfectly, they may be in jeopardy with the space debris. The challenges are the entire approach to space. So thank you very much, Mr. Chairman.

Chairman BABIN. Thank you. I'd now like to call the gentleman from Florida, Mr. Crist.

Mr. CRIST. Thank you, Mr. Chairman. Thank you to the panelists here today to share your expertise with all of us. Mr. Gerstenmaier, NASA has invested significant funds and effort in developing and certifying commercial crew systems. And as you know, this program will ultimately serve as a model for future public/private partnerships for space activities. What lessons have been learned from the Commercial Crew Program and can be applied to deep space exploration?

Mr. GERSTENMAIER. I think there's many, and I can go just through a few. I think first of all it's very important that you have the requirements set up front correctly with the partners. And we did that through a requirements development standpoint. We also allowed for alternate standards which I think is also very important. So we didn't force them to adhere just to our standards, our NASA specifications. We allowed them to provide back to us standards that we initially agreed to up front. And I think that helped to have a very stable understanding of the requirements in place.

I think it's also important that we have the ability to add some additional testing if we see a need for it in the activities. Likewise, we have the ability for ourselves to do testing if it's needed. I think we also learned a lot from the commercial cargo program. We could take significantly higher risk with cargo than we can with the life and humans. That allowed us to gain experience to see what this operating model was like working with two providers. It got us a chance to see where we needed additional insight, and I think that helped us with this program.

I think we're about ready to learn a whole bunch of new lessons as we go into this next phase as we start to close out and to do all the verifications, all the validation activities that were talked about, actually get the hardware through the final testing. I guarantee you we will learn through that and we will put some lessons in place. It's also very important for us to have the two providers as was discussed earlier. That gives us another degree of freedom that if we run into schedule problems with one provider or there's a major failure on their systems, we have another provider. So there's a sense of redundancy. I call it portfolio management by selecting multiple providers that allows us to ensure we get the capability we need at the end. But I think those are some of the major ones. And I can think some more about those off-line.

Mr. CRIST. Great. Thank you, sir. Could NASA leverage the vehicles developed under the Commercial Crew Program to support and accelerate its deep space exploration plans?

Mr. GERSTENMAIER. Again, we can go look at these vehicles' systems design, some of the rockets and other pieces, and see how they might fit in another activity. But as I described to you, regard-

ing lessons learned, we can definitely apply some of those acquisition lessons learned, some of those program project management lessons learned for the new programs as we look to lunar activities in the future.

Mr. CRIST. Thank you. Would any other panelist like to comment on this?

Mr. MULHOLLAND. Yeah, I think it's incredibly important for the partnership and the acquisition approach to be tailored to the specific mission. For commercial crew, I think it was because of our experience in this environment over decades. I think it was the appropriate mechanism. For deep space activity, where there is a lot of research to be done and the requirements by definition can't be stable yet, the approach that they're using is necessarily different.

From a specific vehicle use, our vehicle was specifically designed for the low-Earth orbit mission. We have not looked at what would be required to use it for a deep space mission. Obviously, it would need some modifications to support those different environments.

Mr. CRIST. Sure. And doctor?

Dr. KOENIGSMANN. Regarding SpaceX, obviously we are laser-focused on getting the job right now done and get to the space station by the end of the year. That's the highest priority at SpaceX. But if you look at this capsule, you'll see a lot of actually eight really powerful engines, and those might be useful in other applications, too.

Mr. CRIST. Great. My next question I'd like to direct to the two of you, Mr. Mulholland and Dr. Koenigsmann. A recent study done by a NASA cost analyst, Mr. Edgar Zapata, said that fixed-price space act agreements, as opposed to traditional cost plus-contracting, have reduced cost risks to NASA, the Federal Government, and therefore, the taxpayers at large. Can you discuss your experience with space act agreements and why you believe they are a good tool to encourage innovation and at the same time reduce cost?

Mr. MULHOLLAND. I believe space act agreements have a place, and they were certainly well-utilized in the early development phase of commercial crew. I think it was incredibly important for NASA to go to a far-base contract for the completion of this design and development phase. It is the only way that NASA can leverage contractual requirements on a contractor.

So it is incredibly important for both the contractor and for NASA to be able to do that and to hold the contractor accountable and to allow us to have certainty in requirement stability.

So I would not advocate using space act agreements for future development activities where you're fielding hardware. That said, for early phases, it's very good. Over all, I think the partnership between NASA and the contractors has been excellent and it has grown more rigorous as the fidelity of the program has matured. And I think that was successful.

Dr. KOENIGSMANN. We have overall had a great experience on the Space Act Agreement under COTS, and I think the numbers quoted in this particular article which I really enjoyed, I think we saved—there was a factor of four to ten less I believe than under a traditional cost-plus contract. We believe in particular firm fixed is the way to go. It is milestone oriented and it gives the right in-

centives to the contractor or ask to keep us—I want to say keep us hungry and let us perform at our highest performance level that we have. And I think we've been very successful under this particular model.

Mr. CRIST. Great. Thank you very much. Thank you, Mr. Chairman.

Chairman BABIN. Yes, sir. Thank you. I'd like to call on the gentleman from Florida, Mr. Dunn.

Mr. DUNN. Thank you very much, Mr. Chairman, and I thank the panelists for being here today. It's an exciting time to be in space but not just because of the excitement but because we see a growing presence of private industry in space. And I like it because they are not there for the glory but because it's good business.

In Florida which Space Florida runs the space complex down there, it actually makes money. It runs in the black. So space is good business. And today I'm particularly interested in how these public/private relationships, commercial relationships, are working.

So let me start if I can with Dr. Koenigsmann. You briefly noted in your written testimony that the NASA SpaceX/COTS partnership has the distinction of being this pay-for-performance partnership between government and private business. Can you elaborate more on those innovative, fixed-price, pay-for-performance contracts and how that leverages the private or public investment, and private investment?

Dr. KOENIGSMANN. So for one reason, if in the unfortunate case that we do need a little bit longer, you know, if that happens, that does not increase the cost, for example because the payment is tied to a particular milestone, like a certain test or a flight or something you can actually, you know, put some value to it. So I believe it gives you more control from a taxpayer perspective where the money goes and how the money is split up over, even over a longer period and a rather complex project like Crew Dragon for example.

Mr. DUNN. Actually, so Ms. Chaplain, in general, would you share your feeling about the fixed-price, pay-for-performance contracting and how that, from the government's point of view, GAO's point of view, how that's influenced the cost of the programs and the return on those?

Ms. CHAPLAIN. So they can be a really good approach to follow as long as you do have your requirements defined and you're not asking for the contractor to be inventing too much in the program. If they have to go into a situation where there's a lot of unknowns and nobody knows how long it's going to take to get it done or how complex it's going to be, it'd be very difficult for a contractor to sign up for a fixed-price arrangement. And that's where the government backs off and goes into a cost-plus environment.

And the other issue is as long as—you know, NASA itself has to decide how much control does it want over the situation. How many requirements does it want to specify? How involved in the engineering does it want to be? How much control does it need? So when it feels like it needs more of that control, it's going to also put you back into a cost-plus situation. But in these instances where you can use fixed price, the requirements are known. They can be very good ways to save money.

Mr. DUNN. Thank you. So Mr. Gerstenmaier, in the cost end of the training side, you now have three new, different manned capsules. And I presume your astronauts have to train on each of these. But going forward, how are you going to segment that training? Is it everybody trains on everything or 1/3 here, 1/3 there or how does that work?

Mr. GERSTENMAIER. So we have four astronauts now dedicated to the Commercial Crew Program, and they do—they're in training for the program but they're also going through design reviews, requirements reviews, seeing hardware, et cetera. We'll eventually assign some of that cadre to the two test flights that are upcoming. And for the Orion program, we'll have the other astronaut corps doing that. We also have astronauts training for space station.

So several years before flight, two to three years before flight we'll start designating crews to the individual vehicles that they're going to fly on, the individual systems that they're going to interact with and begin their specific training for those particular missions.

But typically, the crew timeline for training is roughly about two years.

Mr. DUNN. I see. So Mr. Mulholland, in the little time that's left to us, I wonder if you would also comment on the use of these private partnerships and commercial relationships and how well that's working from your point of view.

Mr. MULHOLLAND. It's working excellently. We have a great relationship with Space Florida. We were able to relocate our program down in Florida and use the extensive resources that we have right there at the space coast. So it's a great model going forward.

Mr. DUNN. Thank you very much. Mr. Chairman, I yield back.

Chairman BABIN. Yes, sir. Thank you. And now I'd like to call on the gentleman from Texas, Mr. Veasey.

Mr. VEASEY. Thank you, Mr. Chairman. And I wanted to ask a question specifically to Dr. Sanders. I wanted to know if she could elaborate on why the ASAP views safety culture as critical and why the ASAP remains concerned about the providers' safety cultures and the evidence that you would use to confirm its presence?

Dr. SANDERS. Safety culture, you know, you can put all the requirements you want to on a program relative to safety. You can say you've got to do this, this, this, and this, but if it's not something that the entity embraces itself and really believes, it's important themselves, then it doesn't really work well.

And so it was important to us to see that the commercial providers had this culture embedded in them. There was early on some evidence that there might be a lack, a little bit of a lack in safety culture. We saw a few things that raised a flag for us. And so we wanted to see more insurance that that was there. It doesn't have to be—you know, we were trying to make the point at the time that it isn't that there's any one way that you necessarily make safety happen become a priority. It has to be something that people believe in. And so that was important to us.

Mr. VEASEY. Mr. Mulholland and Dr. Koenigsmann, can you talk about culture surrounding safety at your respective companies and how do you ensure that schedule concerns do not drive decisions that should compromise safety?

Dr. KOENIGSMANN. Yeah, absolutely. Actually, thank you for the opportunity. And I want to point out, I totally agree with Dr. Sanders on this. If you don't have the corporate culture of safety, then all the requirements, they're good but, you know, they're still—you do need the safety culture as a basis to actually create a safe and reliable capsule and launch.

That is actually my job at SpaceX. I'm the head of the flight reliability and build reliability departments. And my job is to make sure that we have a safety culture that translates into quality hardware and that translates into a safe launch.

I use—my method obviously might be different from others, but I use a lot of talking directly to people and then in addition to the formal reviews, I go a lot of side ways into places and talk to the technicians. I look at the capsule. For example, I looked at the Crew Dragon capsules. There's three capsules right now that I saw in the factory, and I talked to engineers and technicians working on it to make sure that they have the right safety culture and understand the significance of flying astronauts. Yeah, absolutely.

Mr. MULHOLLAND. I certainly appreciate the question, Congressman. It's an area I've got a lot of passion around. Our company has essentially grown up with NASA through the human spaceflight program. We've been a trusted partner with NASA on every human spaceflight program that this country has performed. And we're very happy to be able to maintain that.

So culture for us, our culture and our safety focus I think is very strong. It's something that we have across our entire company. You know, our business is to field and deliver transportation platforms. We do it for the commercial aviation sector. We do it for our servicemen and women, and we do it for human spaceflight.

And the way you develop that culture is over time and it's with the decisions that you make. It's how you treat your employees, and it's how you deal with technical issues and having a robust focus on engineering discipline and the safety decisions that you make.

You know, it is something that takes a long time to develop, and it's something that an organization has to be passionate about to maintain. And it's something that I think over decades this company in particular has demonstrated.

Mr. VEASEY. Thank you. Thank you, Mr. Chairman. I yield back.

Chairman BABIN. Yes, sir. Thank you. Now I'd like to call on the gentleman from Indiana, Mr. Banks.

Mr. BANKS. Thank you, Mr. Chairman. So as I understand it, the Mission Management Team historically was in charge of reviewing possible mission issues during and after flight. Members from different areas of NASA sat on the board. The MMT even had a vote in the go/no-go poll before a launch. So the MMT simply functioned as a safety watchdog.

My first question is for Mr. Mulholland and Dr. Koenigsmann. What safety programs are currently in place to match the role previously played by MMT at Boeing and SpaceX? Mr. Mulholland?

Mr. MULHOLLAND. Excellent question. So growing up on the space shuttle program and seeing the foundation of the mission management team approach, our mission management plan is going to mirror that that we implemented on the space shuttle pro-

gram. So we will have a mission management team. NASA will be part of that mission management team. We will have similar reviews heading up to and into launch, both from the flight readiness review and L minus two review before we commit to taking the vehicle. And they will be fully up. The mission management team will be up and running from that FRR on in consistent with how we upgraded the shuttle program.

Mr. BANKS. Okay.

Dr. KOENIGSMANN. Yeah, a slightly different name. On our side we call it flight reliability. But nevertheless, I actually learned from the shuttle obviously, too, and why change something that worked? And so we created a similar approach where we review and test and verify as we go along.

I do want to also, you know, maybe mention that Dragon—not Dragon, Falcon 9 is usually—we can static fire it on the launch pad. So that's a possibility, do a very last test on the last week before launch to make sure that this vehicle is ready to go. It's similar to running up the engines and make sure that the vehicle is ready to go.

So, in addition to, you know, taking the traditional approach as we've added elements there that we think contribute to safety and to reliability.

Mr. BANKS. Okay. Thank you. As a follow-up to that to both of you, who would have the final say on whether or launch in a SpaceX or Boeing vehicle? And would NASA be able to call off the launch or would Boeing or SpaceX have complete authority to decide to launch?

Mr. MULHOLLAND. NASA has the final no-go for flying their crews.

Dr. KOENIGSMANN. Yeah, I believe that's the case on our side, too.

Mr. GERSTENMAIER. NASA has the authority to override the contractor decision to do what's right for the crew.

Mr. BANKS. Okay. Thank you. I understand that SpaceX is planning on water landings while Boeing will be landing vehicles in the desert. What procedures does each company plan to put in place to ensure the safe retrieval of astronauts once they've landed? Mr. Mulholland?

Mr. MULHOLLAND. It is our responsibility, and there is a whole set of NASA requirements on what has to be fielded out of the retrieval site, which includes medical personnel, the ability to transport the astronauts to a local hospital within an hour. There is a whole set of requirements, and we've got the infrastructure in place or in work to support that.

Mr. BANKS. Okay.

Dr. KOENIGSMANN. Yeah, and we obviously got the same requirements from the perspective, and we have a ship. We have the ability to land a helicopter. And we actually, on this particular—the way we get the capsule out of the water, that is something that we do currently on every Crew Dragon last time on Saturday morning or Sunday morning, I think, on the last flight. So it's a routine activity for us, obviously upgraded and with additional personnel to make sure the astronauts are safe.

Mr. BANKS. Okay. Does each company have a plan for emergency landings in areas other than the primary landing site?

Mr. MULHOLLAND. Our plan normally is to land on land because of the trajectory that we fly. If we end up in an abort situation, we will land in the water. We'll be certified for that also.

In the situation of an abort, the NASA and the government forces will do the retrieval.

Mr. BANKS. Okay. Doctor?

Dr. KOENIGSMANN. Yeah, we do rely also on government support in case of, you know, landing in the wrong place or the wrong spot obviously.

Mr. BANKS. Okay. I have a few seconds left. Mr. Gerstenmaier, as NASA continues to buy seats on Russian spacecraft to travel to the International Space Station, will this practice stop once the Commercial Crew Program is ready? Or will NASA continue to purchase seats on Russian aircraft?

Mr. GERSTENMAIER. We will not purchase seats on Russian Soyuz after this program becomes operational. We still will continue to fly our crew on the Russian Soyuz vehicle, and we will fly a Russian cosmonaut on our U.S. crew vehicles. And the purpose for that is to ensure that we always have space station manned with one Russian cosmonaut and one U.S. astronaut so they can operate the appropriate systems. The station requires operations of the Russian segment and the U.S. segment. So we need to have a mixed crew on board. If a contingency occurs, the crew gets in the vehicle they arrived on and they need to return to the earth. So to keep that mix on orbit where we have a Russian cosmonaut and a U.S. crew member, we need to share crews across our vehicles. So our plan is no longer to purchase seats but we will still have the ability, we will still fly a U.S. crew member on a Soyuz and the Russians will likewise fly one of their crew members on our U.S. crew vehicles.

Mr. BANKS. Thank you. My time is expired.

Chairman BABIN. Yes, sir. Thank you. I'd like to recognize the gentleman from Virginia, Mr. Beyer.

Mr. BEYER. Thank you, Mr. Chairman, very much. And thank you all for being with us.

Dr. Koenigsmann, can you give us an update on SpaceX's timetable for a manned spaceflight to Mars?

Dr. KOENIGSMANN. I'm not—I don't think I'm qualified for that. I mean, obviously that is a long-term goal that our founder and CEO, Mr. Musk, has and there's a team working on this. But I want to say it's a relatively modest team, and the main focus on the company is clearly on this particular program and getting to the space station. That is our first step into manned space travel.

Mr. BEYER. My colleague, Mr. Perlmutter from Colorado, has a seat on NASA's 2033 flight to Mars. But we're all——

Mr. PERLMUTTER. I'll go on SpaceX's.

Mr. BEYER. Yeah. If we can get rid of him earlier, that would be very helpful. And you know, one of our previous friends on the Republican side talked about how wonderful it was that we were now in our space industry could make money off it, rather than just doing it for the glory. Tell me, Mr. Koenigsmann, from a SpaceX

perspective, cars aside, is there a viable business model? We know the satellite folks have done really well, the Orbital ATKs.

Dr. KOENIGSMANN. Right.

Mr. BEYER. But can you make money doing these crew missions also?

Dr. KOENIGSMANN. So I want to say we actually brought the commercial space back to the U.S. We had 18 launches in the last year, and I want to say 60-something percent were—of the commercial market is now done by SpaceX. I hope I got my numbers right here. And that obviously is a commercial aspect, and that gives us an additional leg to stand on, notwithstanding that the crew program obviously gets some funds into SpaceX, too.

But I'd want to point out that we are diversified and looking at commercial launches as much as government launches, too. There's additional benefit, of course, for Crew Dragon and the benefit is that we're using the same rocket over and over. There's no change here, and that makes us a very well-practiced team with a lot of experience and a lot of data. I personally have been building rockets for 15 years at SpaceX, and I must say, I learned a lot in particular in the last year just by pure repetitive launches.

Mr. BEYER. That's a good lead-in because we talked a lot about the Soyuz rockets.

Dr. KOENIGSMANN. Right, yes.

Mr. BEYER. And I've toured your facility in California and seen the engines that you built.

Dr. KOENIGSMANN. Yeah.

Mr. BEYER. Can they replace Soyuz?

Dr. KOENIGSMANN. Yes, I think so. I mean, the engines are—we build almost everything basically in-house and the idea is to keep control of costs and schedule if you build it in-house. And it's end to end. It's the launch vehicle all the way up to Crew Dragon. There's no gap here.

Mr. BEYER. Mr. Mulholland, is there an opportunity to work together with SpaceX on the part of Boeing, ULA, et cetera in terms of the engines?

Mr. MULHOLLAND. From a launch vehicle standpoint because we go out and we contract for that launch vehicle service. So we competitively competed for our launch vehicle for the initial phases of commercial crew. For us, Atlas V was the only launch vehicle that had the mission assurance, reliability, and safety record necessary to flight crew. Obviously, if we look at long-term lifecycle affordability, we will continue to look at different launch vehicles in this class, and when one exhibits the safety record and reliability performance that we think is necessary for crew, we'll certainly consider that.

Mr. BEYER. Great. Thank you. Mr. Gerstenmaier, in Congress we're struggling with how to react to the Russian interference in the 2016 election, and we're increasingly realizing that they've interfered in elections all over the world, all over Europe. Have you seen any Russian disinformation interference in the space culture?

Mr. GERSTENMAIER. We've seen no evidence of problems in the space culture. I think as we've described in this hearing, we talked about a safety culture that was required that needs to be in place to ensure safe flight. We have a very strong relationship with our

Russian partners. We share the same strong desire for protecting human life. We work together fairly seamlessly together to work technical problems and issues. We share data back and forth very openly. We recognize the challenges of putting humans in space, both the Russians and the U.S. And so far, the space industry has not been subject to other activities that could be seen as bad. The focus of protecting human life drives us to a higher calling to be more open and transparent than may be normally required.

Mr. BEYER. Great. Thank you very much. Mr. Chair, I yield back.

Chairman BABIN. Yes, sir. Thank you. Now I'd like to recognize the gentleman from Florida, Mr. Posey.

Mr. POSEY. Thank you very much, Mr. Chairman, and thank you, panel for your appearance today.

Mr. Gerstenmaier, on what date does our contract with the Russians to transport our astronauts back and forth to the International Space Station, what is the date of the end of our contract with them?

Mr. GERSTENMAIER. The last launches are in the spring of 2019 with their crew returns in the fall of 2019. So by probably October, November of 2019, we need to have some established way for commercial—the U.S. providers to be delivering crews.

Mr. POSEY. Okay. How many missions do we have between now and then?

Mr. GERSTENMAIER. How man Soyuz missions we have between now and then? We have roughly—we do two Soyuz missions in the spring and two Soyuz missions in the fall. So we fly essentially three crew members in the spring and three crew members in the fall.

Mr. POSEY. Okay. How many do we have scheduled after that?

Mr. GERSTENMAIER. After the 2019 date with Soyuz? We have none.

Mr. POSEY. None? Nothing scheduled for the ISS?

Mr. GERSTENMAIER. We only have what I described before where we will fly one of our astronauts on the Soyuz vehicle for safety considerations and we will fly one Russian on our U.S. crew providers. But beyond that September 2019 date, we have no further ability to use the Soyuz directly for our purposes.

Mr. POSEY. But what is the need for missions to the space station? How many more missions do you think we'll need to have to the space station?

Mr. GERSTENMAIER. Again, we'll need from then through the end, probably 12 missions or so. Again, two per year, same kind——

Mr. POSEY. Two per year for the next——

Mr. GERSTENMAIER. Until the end of station is no earlier than 2024. So that would be 2019 through 2024.

Mr. POSEY. Okay.

Mr. GERSTENMAIER. So five years at two per year.

Mr. POSEY. Okay. Mr. Mulholland, when do you think you're going to be flight-ready?

Mr. MULHOLLAND. We have high confidence in our plan we'll fly our uncrewed flight in August of this year and our crewed flight in November of this year.

Mr. POSEY. So you think you'll be on line by spring of 2019?

Mr. MULHOLLAND. Yes, sir.

Mr. POSEY. Okay. Mr. Koenigsmann, how about you?

Dr. KOENIGSMANN. It's about the same. We have an uncrewed flight in August of this year and then we have a crew flight plan for December this year.

Mr. POSEY. Okay. Just out of curiosity, Mr. Gerstenmaier, what are we paying the Russians per seat now?

Mr. GERSTENMAIER. It's on the order of $70 to $80 million per seat.

Mr. POSEY. Okay. Are they going to pay us when we carry their people up there?

Mr. GERSTENMAIER. No, and we're not going to pay them for them carrying our astronaut to station.

Mr. POSEY. But they won't be carrying our astronauts after 2019, will they?

Mr. GERSTENMAIER. Yes, they will, for the safety reasons I described earlier. We will continue to have one U.S. crew member on every Soyuz flight that flies to station, and we will continue to have one Russian on one of our U.S. flights. And that's to keep station viable with the Russian cosmonaut and a U.S. astronaut aboard station.

Mr. POSEY. And of course——

Mr. GERSTENMAIER. And that will be done under no exchange of funds basis.

Mr. POSEY. All right. So we'll carry ours and at least one of theirs and they'll carry theirs and at least one of ours?

Mr. GERSTENMAIER. That's correct.

Mr. POSEY. Okay. Thank you, Mr. Chairman.

Chairman BABIN. Yes, sir. Thank you. Now I'd like to recognize the gentleman from Colorado, Mr. Perlmutter.

Mr. PERLMUTTER. All right. Thanks, Mr. Chairman. And Mr. Gerstenmaier, let me start with you. In November we talked a little bit about the Dream Chaser, and they were actually having a test flight and drop back in November when we last visited. And can you remind me what it is that NASA has planned for the Dream Chaser? It's primarily cargo. Anything else?

Mr. GERSTENMAIER. It is for cargo and it's both pressurized and unpressurized cargo to the station.

Mr. PERLMUTTER. Is it possible—I guess anything's possible but is it possible it would be a back-up to SpaceX and Boeing?

Mr. GERSTENMAIER. Not at this time because our requirements for safety are dramatically different between the cargo program and the crew program. For the crew program we have a much more stringent requirements in capability. We have a requirement for an abort capability in the vehicles, and currently as Dream Chaser is envisioned for the cargo missions, it doesn't meet fully all those requirements and also it doesn't have an abort capability as it's currently envisioned for cargo.

Mr. PERLMUTTER. But if either of the contractors were to slip up, those kinds of things could be changed I imagine?

Mr. GERSTENMAIER. Through appropriate procurement and competitive procurement activities, yes.

Mr. PERLMUTTER. Okay. Can the panel talk to me about load and go and what that means to all of you and what you expect because—and I'd start with you, Dr. Koenigsmann, if you would.

There's some concerns that have been expressed that when you're fueling the rockets in the spaceship or whatever that, you know, there's a little additional danger at that point. I mean, I'll just open it wide open and start with you, sir.

Dr. KOENIGSMANN. Certainly. I mean, we use what we call densified fuel. It's subcooled actually way below the boiling point, and it's particularly adequate to load it actually fast and quick. And what we tried to do here is we tried to minimize the time the exposed personnel, not just astronauts, but also crew to the hazard of fueling. So in this particular case, our procedure is actually that we put the astronauts—we strap them in. We make sure they're comfortable, and then the ground crew retreats. And we arm the pad abort system that we already tested. And then we start fueling the main propellants basically within the—what amounts to like 1/2 hour, something like that. So it's a relatively quick procedure, and we believe that this exposure time is the shortest possible and therefore the safest approach.

I do want to point out that when you load traditional propellants you basically load them, LOX at least, at their boiling point. So you're constantly refilling while the gas basically goes overboard. It's not—it's described—some people say it is quiescence but it's actually a constantly boiling process that needs to be refilled from the other side. So we don't consider that as a really quiescence stage, either.

Mr. PERLMUTTER. So from SpaceX's point of view, the purpose is——

Dr. KOENIGSMANN. Right.

Mr. PERLMUTTER. —safety?

Dr. KOENIGSMANN. Correct.

Mr. PERLMUTTER. I mean, so you think it's safer to do that. Does anybody else have a comment on load and go? Mr. Mulholland?

Mr. MULHOLLAND. Load and go is an approach that the Atlas V doesn't take, you know, and I think that the Aerospace Advisory Panel, NASA appropriately has significant concerns over that approach. You know, it's something—and obviously I don't know the specifics of the SpaceX system, but using densified propellant was something that we considered years ago in the space shuttle program when we were looking for additional performance capability. But we never could get comfortable with the safety risks that you would take with that approach.

When you're loading the densified propellant, it is not an inherently stable situation. With the approach that the shuttle took, the approach that the Atlas V takes, you do load the propellant and then you enter into a period called stable replenish because that system then is thermodynamically stable. So you are flowing a small amount of propellant in just to maintain that thermodynamic stability.

So you know, I have great trust in ASAP and NASA and working with SpaceX to determine that, whether that is technically and from a safety standpoint feasible.

Mr. PERLMUTTER. Quickly, Mr. Gerstenmaier? Dr. Sanders? Just quickly.

Mr. GERSTENMAIER. Yeah. What we'd like to do is not have kind of a word discussion about where this is, but we're going to actually

take the vehicle design, we're going to go look at the specific hazards associated with the various phases during loading. We'll look at when the crew goes on board. We'll look at what those hazards are, what the likelihood of those hazards are, and we'll make an informed decision about when for this particular rocket's design is the safest time to put the crew on orbit.

So rather than picking words such as load and go or stable replenish, we're not going to do that. We're going to go below that. We're going to understand the specific risk and understand the specific timeframes that the crews are exposed to hazards, and then we'll make an informed decision about the appropriate time to go ahead and put the crew on orbit.

It's also important that if we stay with the same approach that SpaceX is using for their cargo flights, we gain a lot of experience of understanding how this rocket gets loaded, how the ground systems operate, the loading systems on the ground, how reliable they are, how safe they are, et cetera. That's an important consideration as well. It's not only the rocket that can damage and hurt the crew. Also the ground system can have problems and failures that can also hurt the crew. We need to look at it in an integrated system. We have the plans in place to methodically review this, look at the hazards, and find the appropriate time to put the crew on board the vehicles. And we'll do that at the appropriate time.

Chairman BABIN. Thank you, Mr. Perlmutter. I appreciate it. Your time's expired. And I just want to thank the witnesses for your valuable testimony and the Members for all of your questions. The record will remain open for two weeks for additional comments and written questions from Members. And I'm not going to be able to shake your hands because I've got to run to another event, but I want to say thank you so very much. This has been very, very informative. Two great companies, and we appreciate all this information. Thank you. This is adjourned.

[Whereupon, at 12:08 p.m., the Subcommittee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Mr. William Gerstenmaier

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"An Update on NASA Commercial Crew Systems Development"

Mr. William Gerstenmaier, Associate Administrator, HEOMD, National Aeronautics and Space Administration

Questions submitted by Ranking Member Ami Bera, House Committee on Science, Space, and Technology

1. During your oral testimony, you stated, "We are brainstorming ideas to provide additional schedule time, if needed. Additionally, as we do this, we are looking for ways to allow the partners to reach an operational tempo after certification." Please provide details on the options being considered to provide additional schedule time and ways to allow the partners to reach an operational tempo.

   Answer: NASA is considering extending the length of the crewed test flights which could provide some additional flexibility for mission planning. Other options are not mature at this time.

   a. How will those options be evaluated?

      Answer: The primary considerations will be the ability of the option to mitigate schedule issues, cost and risk.

2. During the Space Shuttle Program, NASA investigated increasing lift performance by using densified propellants. Please explain why NASA considered the use of densified propellants on the Space Shuttle and why NASA decided against its use. What were the concerns relative to safety? What other concerns led to the decision not to use densified propellants on the Space Shuttle?

   Answer: NASA did investigate the use of densified (i.e. superchilled) propellants as early as the 1970s, and revisited the idea in the 1990s as a potential way to increase the performance of the Space Shuttle. Ultimately, the decision to pursue other opportunities was based, not on safety, but on the technical difficulty (and likely associated cost and schedule impacts) of certifying components and systems able to handle densified propellants into the existing Shuttle system.

   On the vehicle side, the multitude of pumps, complex propellant lines, and main engines on the Orbiter were all originally designed and built for "normal" cryogenic propellant temperatures; the challenges of re-testing and recertifying this entire system at densified propellant temperatures would have been substantial and disruptive to Shuttle flight operations.

Operationally, the Shuttle ground systems at the Kennedy Space Center would have also required significant modifications to facilities and procedures to tank and maintain densified propellant temperatures.

In the end, other technical solutions (such as the introduction of the Super Lightweight External Tank and increased Space Shuttle Main Engine performance) obviated the need for densified propellants, and increased Shuttle performance to the point which would enable Shuttle to deliver and assemble the large elements in the high inclination orbit of the International Space Station.

3. During the question and answer session of the hearing, you stated that "we will find the appropriate time, along with the contractors, to put crew on this particular vehicle design that is most appropriate for the lowest risk to the crews."

   a. Do I understand correctly that NASA's sole question regarding SpaceX's use of densified propellant is "when" crew would be put on board the Crew Dragon and not "if" NASA will accept the risks associated with loading propellants while crew are onboard?

      Answer: NASA is evaluating the appropriate time, to be determined by a thorough analysis of risks, to put crew on board for SpaceX's specific system design. Risks need to be considered not only for the flight crew, which has the option for rapid egress utilizing the launch abort system, but also for the safety of crews on the ground during fill operations. There is no scenario without risk. NASA will conduct a thorough trade study analyzing the overall risks and make an informed decision on the timing of crew and propellant loading. This analysis is in work and data from cargo flights is actively being utilized in this analysis.

   b. Is NASA working with both providers to determine the appropriate time to put crew on the vehicles, as you indicated during the hearing discussion? If so, is there a question as to when crew would board the Starliner crew vehicle, which would launch on the Atlas 5 launch vehicle?

      Answer: Crew ingress timelines for Boeing's crew transportation system have already been baselined. Crew ingress will occur after propellant has been loaded on the launch vehicle.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"An Update on NASA Commercial Crew Systems Development"

Mr. William Gerstenmaier, Associate Administrator, HEOMD, National Aeronautics and Space Administration

Questions submitted by Ranking Member Eddie Bernice Johnson, House Committee on Science, Space, and Technology

1. According to a NASA document, gaps in the U.S. crewed presence on the ISS "at any point would diminish vehicle operations to an inoperable state." If that is the case,

    a. When is the last Soyuz flight with a NASA crew seat paid for by NASA scheduled?

    Answer: The last scheduled Soyuz flight with a NASA crew seat paid for by NASA is currently scheduled to launch in May 2019 and return in November 2019.

    b. By when would a post-certification commercial crew transfer mission need to occur to prevent any gaps in U.S. crewed presence?

    Answer: At this point, given current schedules and plans, the first post certification commercial crew mission would need to occur in the fall 2019.

    c. What is NASA's contingency plan if the commercial crew providers are not ready to be operational by the time we use the last Soyuz seat purchased from Boeing?

    Answer: NASA is in the process of developing options to provide additional schedule time. NASA is considering extending the length of stay aboard the ISS for the crewed test flights, which could provide some additional flexibility for mission planning. Other options are not mature at this time.

2. Both Boeing and SpaceX are currently planning for a crewed flight test in 4th quarter 2018 and certification review in 1st quarter 2019. That schedule would allow just a matter of a few months between the crewed test flight and final certification.

    a. What activities need to be completed by NASA and the contractors between the crewed flight test, and the certification review?

    Answer: All data from the crewed test flight will need to be reviewed and evaluated. If there are any anomalies during the flight, they will have to be

evaluated and addressed. An Operations Readiness Review milestone must be successfully completed post-crewed test flight prior to certification for both companies. Also, a final human rating certification package will need to be approved by NASA.

b. Are both providers allowing adequate time in their schedules to complete these activities? If yes, what is the basis for that determination?

Answer: The partner schedules are aggressive, but achievable. NASA independently reviews and evaluates the partner schedules on a monthly basis. NASA will make sure that the proper time is allocated for these activities.

3. Will all Commercial Crew Program crew be fully trained on both the Starliner and the Crew Dragon? How will NASA handle crew assignments if one vehicle is not flight ready or experiences a significant delay?

Answer: For crewed test flights, NASA will make specific crew assignments from the current crew cadre. Crewmembers are trained specifically for the test flight on that particular vehicle. For operational flights, ISS crew are trained in detail for the vehicle they are assigned to. However, all crewmembers will have basic familiarization and emergency training for all vehicles docked at ISS.

NASA does not anticipate that schedule delays will affect the crew assignments.

4. During the hearing, you indicated that NASA would continue to fly astronauts on Soyuz spacecraft and mentioned that, in turn, NASA would provide a seat to a Russian crewmember on U.S. commercial crew vehicles once they are operational. You noted that the exchange of seats is for safety considerations and to ensure that a mixed U.S. and Russian crew is maintained on the ISS. When do you anticipate that a seat on the Soyuz, under a no-exchange-of-funds arrangement, will first be used?

Answer: According to current flight planning, we anticipate a U.S. crewmember flying on a Soyuz under this new model to launch in September 2019.

Responses by Mr. John Mulholland

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"An Update on NASA Commercial Crew Systems Development"

Mr. John Mulholland, Vice President and Program Manager for Commercial Programs, Boeing Space Exploration

Questions submitted by Ranking Member Ami Bera, House Committee on Science, Space, and Technology

1. Will your flight demonstration mission be a comprehensive demonstration of all systems and functions of the operational vehicle? If not, what won't be demonstrated?

   Answer: We think it's incredibly important to "test as you would fly." That's why the Orbital Flight Test of the CST-100 Starliner will put every aspect of the Starliner's mission profile to the test ahead of crew flights. This includes testing the Starliner's Environmental Control and Life Support Systems (ECLSS) and ability to autonomously rendezvous and dock to the International Space Station. Unlike transportation systems of the past, the Starliner is a "full service" system. It provides all elements needed to transport crew and cargo to and from the International Space Station, including crew training and mission planning; spacecraft assembly, integration and testing; cargo integration; launch vehicle integration and testing; ground, launch and mission operations; and crew and cargo recovery. At Boeing, we don't take this "full service" responsibility lightly and have done everything we can to ensure a full-up test of the system is conducted before astronauts take flight.

2. In your prepared statement, you state that "We are well aligned with our customer on crew safety and mission assurance, and our analyses show that we exceed our requirements for crew safety." Please explain how you are exceeding requirements for crew safety, especially given the fact that the ASAP is indicating that both providers will be challenged to meet Loss of Crew requirements.

   Answer: We appreciate the reviews, findings and feedback from the ASAP and all of NASA's advisory committees and accountability agencies. They compelled us to take a look at the high risk areas and either design them out, perform additional testing or add in redundancies. We've driven those high risk areas to closure and are proud to say that we will exceed NASA's Loss of Crew requirements. With that said, even one fatality is unacceptable, regardless of number of flights or projections. That's why we continually work with NASA on our first and most important priority – safe crew transportation to and from the International Space Station. NASA personnel have been embedded with our teams throughout Starliner development, which has helped provide transparency to our customer as we keep safety first in all that we do on this program.

a. Do you have any information on the analyses that show you are exceeding requirements for crew safety that you could provide to the Subcommittee for the record?

Answer: We have completed the final design analysis and are compliant in all of NASA's contractual Loss of Crew (LOC) and Loss of Mission (LOM) requirements. In fact, we not only meet the 1/270 LOC requirement, we have consistently exceeded that number for about a year and a half even as new test data is injected into our risk assessment system. We delivered the Integrated Probabilistic Risk Assessment (PRA) report to NASA as a deliverable under the contract (DRD-112) in December 2017. In addition, we submitted the following supporting data to NASA:

- Event trees
- Fault trees
- Hazard analysis
- Subsystem reports
- Crew survivability reports

3. Given that the operational life of the International Space Station is currently planned to run until 2024, and given that you had planned on flying years sooner than is now projected, will you be able to get enough of a return on your investment to justify your involvement?

Answer: We are strong advocates for extending the life of the International Space Station. The research performed on board the world-class space laboratory is benefitting life on Earth and increasing our chances of success as we prepare to explore deep space. At the same time, it is synergistically providing the vital infrastructure necessary for the commercial transportation market to emerge. That market cannot, and will not, take off unless we have uninterrupted human presence in low-Earth orbit, beginning with the International Space Station and continuing on with new government, commercial or private destinations.

4. With respect to Boeing's culture to promote safety, what specific steps have you taken to ensure that there are opportunities for dissenting voices, alternative technical views, and independent technical analysis on the development of the Starliner crew capsule?

Answer: At Boeing, we have a safety culture that is foundational to the Boeing brand and implemented on our Commercial Crew Program by leaders and employees with extensive experience in human spaceflight systems development and operations. We have fostered an environment in which any employee at any level of the organization can speak up if there's an issue. We also have several independent analysis teams, both inside and outside the company, that have access to our progress, challenges and schedule.

- The Program System Safety team is separate from the Program Engineering and Production teams, which allows it to provide an independent assessment of the safety hazards associated with the vehicle design, manufacturing, and test program.
- The Hazard Reports developed by the Program System Safety team are reviewed and approved by NASA's Commercial Crew Program Safety Review Board and the International Space Station Safety Review Panel.
- Boeing also has strong Engineering and Safety & Mission Assurance Organizations independent of the Commercial Crew Program that review engineering products at key program milestones, such as Design Reviews, Enterprise Gate Reviews, Safety Reviews, and Certification Reviews, to ensure technical integrity and to independently assess the level of technical risk incurred throughout the lifecycle of the program. Based on their findings, these independent reviewers may assign actions, elevate their concern to the appropriate management levels, or solicit additional technical help to support risk reduction. These reviews apply accumulated corporate expertise to areas deemed critical to program success and seek to validate engineering assumptions, design solutions, production approaches, testing and verification plans, and operations and maintenance approaches.
- NASA has complete transparency into our development process and we have NASA employees embedded on our team so at all times they are reassured that our spacecraft will be safe for their astronauts. Those employees are involved in the day-to-day insight and technical interchange, as well as oversight of key development tests and events.
- We also provide NASA's safety advisory groups and government accountability agencies (Aerospace Safety Advisory Panel, NASA Advisory Council, Government Accountability Office, Office of Management and Budget, etc.) the appropriate level of access into our design, systems, processes and procedures so that they can perform independent assessments of our risks. Their reviews, findings and feedback continue to add value to the development of the CST-100 Starliner.

5. During the question and answer session of the hearing, the question was asked as to what Boeing's investment has been in the development of the Starliner crew vehicle. Please provide the magnitude and details of that investment.

   Answer: While we are unable to provide detailed financial information, we can tell you that we've made a significant investment in the program. Boeing is committed to the program's success and accepted the risk associated with a firm, fixed-price development environment, where the market for future services beyond NASA is still in its very early stages.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"An Update on NASA Commercial Crew Systems Development"

Mr. John Mulholland, Vice President and Program Manager for Commercial Programs, Boeing Space Exploration

Questions submitted by Representative Frank Lucas, House Committee on Science, Space, and Technology

1. After your respective companies are ultimately successful in creating a new vehicle for human spaceflight, both will obviously receive dividends for years to come. The question of how much "skin in the game" each of your companies has in the commercial crew program has been raised in the past, and at the time, NASA mentioned that they were responsible for somewhere between 80 and 90 percent of the total cost of this program. Could you tell me what percentage of the cost your company has covered in the commercial crew program?

   Answer: While we are unable to provide detailed financial information, including a percentage of the total value of the contract, we can tell you that we've made a significant investment in the program. We value that we bring comes in the breadth of resources that Boeing has poured into this program, ranging from engineering and operations to safety reviews and issue resolution. Additionally, our experience across system design elements and corporate relationships with the U.S. supply base has enabled us to negotiate best value from the nation's premier aerospace providers and more effectively manage performance, to the benefit of NASA.

Responses by Dr. Hans Koenigsmann

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"An Update on NASA Commercial Crew Systems Development"

Dr. Hans Koenigsmann, Vice President of Build and Flight Reliability, Space Exploration Technologies

Questions submitted by Ranking Member Ami Bera, House Committee on Science, Space, and Technology

1. In the minutes of its October 2017 meeting, the ASAP noted the cooperative nature of the analysis conducted by SpaceX and NASA into an anomaly, specifically focusing on the composite overwrapped pressure vessels (COPV).

   a. What is the status of the COPV redesign? Is the redesign complete, and if not, when do you anticipate it will be certified for use?

      Answer: The COPV redesign is complete, and the qualification is progressing well. SpaceX has nearly completed all qualification activities for the system, which will be in operation in the first half of 2018. We are working closely with NASA to ensure timely certification for crew.

   b. How does SpaceX plan to certify the redesigned COPV?

      Answer: SpaceX is working closely with NASA to further enhance the robustness of our composite overwrapped pressure vessels (COPVs) and to ensure NASA is comfortable with the system's performance in a variety of flight environments. Both SpaceX and NASA are independently and collaboratively reviewing the system to certify it for flight. SpaceX is confident that this process is safe, and we are working closely with NASA to complete the ongoing, rigorous analysis necessary to achieve certification.

      Dr. Patricia Sanders, chair of the NASA Aerospace Safety Advisory Panel (ASAP), noted in her testimony before the Space Subcommittee that "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."

c. Is the redesigned COPV required for the uncrewed and crewed demonstration test flights?

Answer: SpaceX uses a common Falcon 9 configuration for all missions. Accordingly, the redesigned COPV will be utilized in all SpaceX missions, including the uncrewed and crewed demonstration flights. This allows the updated design to rapidly accumulate significant flight heritage and improve confidence in mission success.

d. Once the redesigned COPV is available, how many non-NASA Falcon 9 flights with the new design will SpaceX need to fly to fully demonstrate to NASA the safety of the COPV? When are those flights projected to occur?

Answer: SpaceX has a robust manifest of more than two dozen missions in 2018, most of which are for customers other than NASA. SpaceX intends to fly multiple missions in the crew configuration of Falcon 9 prior to conducting the test flight with crew later this year, and are working closely with NASA to determine the right number.

2. I understand that last July SpaceX announced it is no longer pursuing a propulsive landing capability for the Dragon capsule, which sounds like a major design change. SpaceX is also having to redesign its COPV tank for the Falcon 9.

a. What are the schedule challenges to accommodating such significant changes a year before your first flight, and what, if any, schedule related concerns do you have going into the flight demonstration program?

Answer: There is no major design change to the system associated with a water splashdown. SpaceX and NASA had always intended to softly land Crew Dragon in water for its initial missions and as a backup to land landings. Propulsive landing capability would not have been utilized until program outyears. Accordingly, there are no schedule challenges associated with landing in water.

SpaceX has a robust plan to meet its milestones for uncrewed and crewed test flights in August and December, respectively.

b. What schedule margin are you holding against the current flight demonstration dates?

Answer: SpaceX is progressing well with sufficient margin toward a test flight without crew in August and a test flight with crew in December. However, SpaceX's top priority is always safety, and we will fly only when both we and NASA are comfortable with the system.

c. Will your flight demonstration mission be a comprehensive demonstration of all systems and functions of the operational vehicle? If not, what won't be demonstrated?

Answer: The two demonstration missions will comprehensively test the systems and processes associated with safely launching, operating, and recovering Dragon 2. The primary distinction between these missions and operational flights will be duration. These tests will last up to a week in duration, while operational flights will have a six month mission operation period from launch to splashdown, with Dragon 2 docked in a quiescent state to the Space Station.

3. Ms. Chaplain stated in her prepared statement that design changes have been made to eliminate turbine cracks in the SpaceX Falcon 9 launch vehicle that NASA determined to be unacceptable for human spaceflight. However, Ms. Chaplain also stated that the risk will not be closed until qualification testing is completed for the redesigned turbine, currently expected in the first quarter of this calendar year. Can you describe the new turbine design and what the qualification testing will involve?

Answer: SpaceX and Commercial Crew Program engineers continue to work collaboratively to identify and mitigate any possible concerns with turbopump cracking. As you note, a very small number of SpaceX turbopumps experienced some minor cracking, a common occurrence with many rocket engines including those that flew on the Space Shuttle. These cracks were within engine design constraints and would not have posed a risk to flight. Both NASA and the Air Force were comfortable with them for satellite launches. However, for crew flights, NASA requested that SpaceX eliminate cracking as an extra measure of mission assurance. We have since addressed this concern with design changes and validation tests, and we fully expect our Merlin engines will meet NASA's robust crew safety requirements.

4. With respect to SpaceX's safety culture, what steps have you taken to ensure that there are opportunities for dissenting voices, alternative technical views, and independent technical analysis on the development of the Crew Dragon crew capsule?

Answer: Safety and mission success are SpaceX's top priorities. The company has a robust mission assurance culture to incorporate a broad variety of inputs both from company employees across multiple engineering disciplines and from external stakeholders.

SpaceX is keenly aware and deeply appreciative of NASA's significant institutional and technical knowledge with regard to human spaceflight safety. SpaceX collaborates with NASA to incorporate these lessons into the crew transportation system. SpaceX manages

weekly, monthly, and quarterly risk review meetings with program officials to provide key insight into any potential risks and the steps SpaceX is taking to mitigate them.

Furthermore, in 2012, SpaceX established an Independent Safety Advisory Panel composed of leading human spaceflight safety experts, including several former NASA astronauts and senior NASA officials. The panel has provided independent and objective assessments of the safety of SpaceX's crew transportation system for human spaceflight to help SpaceX maintain the highest commitment to safety.

5. During the question and answer session of the hearing, the question was asked as to what SpaceX's investment has been in the development of the Crew Dragon vehicle. Please provide the magnitude and details of that investment.

Answer: SpaceX operates under a $2.6 billion firm fixed-price (FFP), Commercial Crew Transportation Capabilities (CCtCap) contract to upgrade the Dragon spacecraft to carry crew and conduct two test missions and six operational missions. Boeing operates under a $4.2 billion firm fixed-price contract. The nature of these FAR-based FFP contracts does not require significant private investment.

Regardless, SpaceX has invested significant funds toward the development and safe operation of the Crew Dragon spacecraft. The Commercial Crew Integrated Capabilities (CCiCap) and Commercial Crew Development Round 2 (CCDev 2) Space Act Agreements (SAAs) required private investment. This is a key benefit of using SAAs, as highlighted by NASA, the GAO, the NASA Inspector General, and other independent authorities.

Crew Dragon is an upgraded configuration of the current Dragon used to carry critical cargo and scientific experiments to and from the International Space Station. Dragon was developed under the Commercial Orbital Transportation Services (COTS) Program. Under the COTS SAA, SpaceX invested more than $500 million toward to development of the Dragon / Falcon 9 space transportation system, far exceeding NASA's $396 million contribution.

SpaceX has also invested significant private capital in enhancing the Falcon 9 launch system used to carry the Crew Dragon spacecraft and associated ground systems. Falcon 9 today can carry more than two times the payload to orbit than the configuration used on the first flights used to carry Dragon in 2010. Falcon 9 is also the world's only operating launch system with reusability capabilities. Furthermore, SpaceX has invested more than $100 million to enhance Launch Complex 39A, which will serve as the launch site for Commercial Crew missions.

6. Given that the operational life of the International Space Station is currently planned to run until 2024, and given that you had planned on flying years sooner than is now projected, will you be able to get enough of a return on your investment to justify your involvement?

   Answer: Yes. SpaceX believes that we will secure a return on our investment in this program through the current planned life of the International Space Station (ISS). SpaceX is proud to partner with NASA to safely carry crew and cargo to and from the ISS. The ISS should be operated as long as it is safe to do so, and the United States should maintain an uninterrupted human presence in low Earth orbit, whether on the International Space Station or commercial habitats.

   The Crew Dragon system can also be used for NASA missions beyond low Earth orbit, including cargo resupply and missions with crew to lunar habitats.

7. During the question and answer session of the hearing, Rep. Foster asked about loss of crew and loss of mission. During that discussion, you referenced the launch escape system. How is the launch escape system activated and employed and how much time is required for the entire activation and deployment process? In the case of the F9-29 launch mishap that occurred on the launch pad just prior to a static firing test of the Falcon 9's engines, would the launch escape system have been able to deploy in time to avoid damage to the capsule?

   Answer: The Falcon 9 has an advanced failure detection, isolation, and recovery (FDIR) system. In the event of any major launch vehicle anomaly, the launch escape system will automatically activate within a fraction of a second, rapidly propelling the Dragon 2 spacecraft away from the launch system.

   Had Crew Dragon been on the launch vehicle during the September 2016 static fire anomaly, the system would have carried onboard astronauts to safety.

   In fact, SpaceX tested for this exact contingency in May 2015 with the successful Pad Abort Test. For this major milestone, SpaceX integrated the full Launch Escape System, including all eight engines, into a flight test vehicle in order to demonstrate the system's capabilities. This crucial real-world test simulated a launch pad emergency that would require rapid escape of the flight crew. The full-scale spacecraft used included a flight-like propulsion system, primary structure, avionics system, and parachute system to demonstrate integrated escape and recovery systems. Within a fraction of a second of receiving the abort command, Crew Dragon's SuperDracos reached full thrust and pushed the spacecraft away from the launch site. The spacecraft reached an altitude of over a kilometer before deploying its parachutes and safely splashing down in the Atlantic Ocean, as intended.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"An Update on NASA Commercial Crew Systems Development"

Dr. Hans Koenigsmann, Vice President of Build and Flight Reliability, Space Exploration Technologies

Questions submitted by Representative Frank Lucas, House Committee on Science, Space, and Technology

1. After your respective companies are ultimately successful in creating a new vehicle for human spaceflight, both will obviously receive dividends for years to come. The question of how much "skin in the game" each of your companies has in the commercial crew program has been raised in the past, and at the time, NASA mentioned that they were responsible for somewhere between 80 and 90 percent of the total cost of this program. Could you tell me what percentage of the cost your company has covered in the commercial crew program?

   Answer: SpaceX operates under a $2.6 billion firm fixed-price (FFP), Commercial Crew Transportation Capabilities (CCtCap) contract to upgrade the Dragon spacecraft to carry crew and conduct two test missions and six operational missions. Boeing operates under a $4.2 billion firm fixed-price contract. The nature of these FAR-based FFP contracts does not require significant private investment.

   Regardless, SpaceX has invested significant funds toward the development and safe operation of the Dragon 2 spacecraft. The Commercial Crew Integrated Capabilities (CCiCap) and Commercial Crew Development Round 2 (CCDev 2) Space Act Agreements (SAAs) required private investment. This is a key benefit of using SAAs, as highlighted by NASA, the GAO, the NASA Inspector General, and other independent authorities.

Responses by Dr. Patricia Sanders

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"An Update on NASA Commercial Crew Systems Development"

Dr. Patricia Sanders, Chair, NASA Aerospace Safety Advisory Panel

Questions submitted by Ranking Member Ami Bera, House Committee on Science, Space, and Technology

1. In response to ASAP's recommendation in February 2017 to produce verifiable evidence of the practice of rigorous, disciplined, and sustained systems engineering and integration principles in support of certification, NASA developed an action plan. However, ASAP's 2017 Annual Report suggests that the Panel remains concerned about whether or not the plan would be successful. What are the Panel's concerns with the contractors' systems engineering and integration practices and why did the Panel raise questions about NASA's action plan? What do the contractors and NASA need to do to alleviate the Panel's concerns?

   Answer: The Panel noted that a common theme in the previous commercial provider mishaps could be traced to escapes in the systems engineering and integration (SE&I) process and the controls involving design, analysis, manufacturing, quality control, qualification, and operations. We believe it is important that a rigorous and disciplined SE&I process be in place, and that it be shown to be effective over time. We do believe that disciplined processes can be applied by providers employing non-traditional approaches. NASA's action plan asserts the ability to verify and/or validate that SE&I principles are followed through contract requirements, deliverables, and increased insight. The ASAP commends NASA for its actions and its acknowledgement of the need for increased surveillance, but the Panel maintains that it is necessary for each provider to internalize the value of highly disciplined providers and controls and engrain them into the company culture. We intend to hold this recommendation open until we see evidence of achieving this outcome.

2. In addressing the issue of fueling the SpaceX Falcon 9 launcher with astronauts on board, often referred to as "load and go", the ASAP annual report for 2017 advises NASA not to discount the other potential hazards associated with loading cryogenic propellants—particularly Liquid Oxygen (LOX). The ISS Advisory Committee chaired by Ret. General Stafford also raised serious concerns about "load and go", as expressed in his 2015 letter to NASA.

   a. Has the ASAP met with General Stafford to examine his Committee's concerns? If not, why not? What NASA actions would address your and the ISS Advisory Committee's concerns? What further analysis is needed to understand and mitigate the risks associated with load and go?

b. In her prepared statement, Ms. Chaplain stated that NASA has informed SpaceX that it will need to demonstrate loading at the pad five times before the first crewed test flight. Does just completing five demonstrations satisfy ASAP's concerns?

Answer: The ASAP conducted a joint insight review of the Commercial Crew Program's certification process and progress with General Stafford's Committee following his letter of concern. Subsequently, it was arranged for General Stafford to receive another in-depth update on the status of certifying the Space X launch vehicle. General Stafford and I periodically discuss our respective evolving assessments on this issue by telephone. I will not attempt to speak for him as to what specific actions would alleviate his ISS Advisory Committee's concerns. The ASAP believes that adequate understanding of the behavior of the Composite Overwrap Pressure Vehicle in cryogenic oxygen is absolutely essential to potential certification for human space flight. In addition, we believe NASA should understand how the system functions in the dynamic thermal environment associated with "load and go" so that previously unidentified hazards can be discovered. This is not a trivial effort. Despite testing at the component and subassembly level, systems often display "emergent behavior" once they are used in the actual operational environment. Any risk determination associated with "load and go" could have significant uncertainty, so demonstrating a disciplined and repeatable process of loading at the pad would be an important component in the decision process, but only one of the factors that NASA needs to carefully weigh. But you can be successful five times and still have very little margin in the system/process so it remains important to understand the hazards, controls, and safety margins within which you are operating.

3. In its recently released Annual Report for 2017, the ASAP recommends that the National Transportation Safety Board 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, ASAP recommends using an independent, standing mishap investigation body based on the existing Mishap Interagency Investigation Board (MIIB) model. Please elaborate on that model, the nature of its inter-agency composition, to whom it would report, and how would it work.

   Answer: Attached is a document with general information on the charter and composition of the existing MIIB. The ASAP has proposed this as a model, not necessarily identical, for an independent standing mishap investigation body. We have proposed that the inter-agency composition be expanded to include, at least, a standing member from the National Transportation Safety Board and the Federal Aviation Administration. The Board could be chaired by an individual appointed by the President, the Congress, or by the members of the Board itself.

4. During the question and answer session of the hearing, you indicated that "The RD-180 data or lack thereof for the launch vehicle for the Boeing variant…has been resolved by finding an alternative way to get insight into that design." Could you please elaborate on the alternative means being used to get insight into the Russian RD-180 engine?

   Answer: The traditional approach used by NASA to certify the launch vehicle would have included a detailed review of the design materials which were not releasable directly to NASA, thereby hindering their certification process. The alternative approach involved a cooperative effort between the NASA Commercial Crew Program, the Launch Services Provider, the United States Air Force, and the National Reconnaissance Office to review all available data including multiple sources such life testing, engine hot fire functionality, performance margins, issue reports and anomaly tracking. This was followed by deep dives into hazard reports and component level qualification – both of which have been completed. There is some final CCP certification work still to be completed, but the plan for accomplishing this is sound.

NASA Human Exploration
Mishap Interagency Investigation Board (MIIB)
Background Information for Members

In the case of a high-visibility, mission-related, human space flight mishap, the NASA Administrator may activate the Mishap Interagency Investigation Board (MIIB). Activation is anticipated for events involving serious injury or loss of life, significant public interest, and other serious mishaps. Since its inception, the MIIB has been called upon to conduct one investigation – the loss of the Space Shuttle *Columbia* in 2003. Within hours of the *Columbia* accident, the MIIB (subsequently known as the *Columbia* Accident Investigation Board (CAIB)) held its first teleconference with all members participating. The final report of the CAIB was published seven months later.

The MIIB consists of a minimum of seven full time members, and is supported by the NASA Headquarters Human Exploration and Operations Mission Directorate (HEOMD) and technical consultants as required. The MIIB consists of the following standing membership:

Board Chair — Appointed by the NASA Administrator

Board Members

1. Commander, Naval Safety Center
2. Commander, Air Force Flight Test Center
3. Commander, Air Force Safety Center and USAF Chief of Safety
4. DOT National Expert on Aviation Human Factors
5. FAA Office of Accident Investigation
6. Commander, 14th Air Force
7. NASA Field Center Director or NASA Program AA (Non-HEOMD or Non-Mission-Related)

The MIIB has its origins within the lessons-learned from the investigation of the Space Shuttle *Challenger* accident in 1986. It was chartered by NASA with White House approval in 1995 (see **Attachment A** for history).

Though originally chartered to address Space Shuttle accidents, members agreed in the past to extend the MIIB's scope to address all human spaceflight accidents. This is being codified in an all-services standard currently undergoing final internal Air Force review prior to full DoD review and approval (Air Force Instruction 91-206, AR 95-30, OPNAVINST 3750.16C, COMDTINST 5100.28). This update to AFI91-206 is being coordinated by the Air Force Safety Center.

The charter of the MIIB is included as **Attachment B**. **Attachment C** includes the current member contact information.

Attachment A
Origins of the Mishap Interagency Investigation Board

When the *Challenger* accident occurred, NASA convened a Mishap Investigation Board, following the guidelines of the Space Shuttle Contingency Action Plan (CAP). When NASA learned that a Presidential Commission was being formed to investigate the accident, NASA opted to put the mishap board's activities on hold until the Presidential Commission was formed. When the Presidential Commission, or Rogers Commission, began their investigation, NASA disbanded its Mishap Investigation Board.
Post-*Challenger*, the process of how NASA responded to mishaps changed. NASA came away from the *Challenger* accident with a renewed motivation of not only maintaining an up-to-date CAP but to also be very proactive in its execution. The two most important changes to the CAP supporting this philosophical change were the formation of (1) a Headquarters Contingency Action Team (HCAT) and a (2) Standing Mishap Interagency Investigation Board (MIIB).

When the Associate Administrator for Space Operations declares a high-visibility mishap (Mishap, regardless of the amount of property damage or personnel injury, that NASA Leadership judges to possess a high degree of programmatic impact or public, media, or political), the Administrator can authorize the activation of the HCAT to help focus Headquarters capabilities on an accident investigation. This ensures that needed personnel and financial resources are quickly and efficiently applied to the investigation, and the relaying of accident investigation information to NASA's stakeholders is done with a high level of accuracy and consistency. The HCAT membership is pre-identified in the CAP as a group of senior NASA Headquarters managers and includes, as a minimum:

1) Administrator
2) Deputy Administrator
3) Associate Administrator
4) Chief of Staff
5) Deputy AA/ADA
6) White House Liaison
7) Chief Engineer
8) Chief Health and Medical Officer
9) Chief Safety and Assurance Officer
10) Deputy Chief Safety and Mission Assurance Officer
11) General Counsel
12) Associate Administrator for Communications/NASA Press Secretary
13) Associate Administrator for International and Interagency Relations
14) Associate Administrator for Legislative and Intergovernmental Affairs
15) Associate Administrator for Human Exploration and Operations (HEO)
16) HEO Deputy Associate Administrator
17) HEO Deputy Associate Administrator for Policy & Plans
18) International Space Station Technical Authority

The goal is to quickly determine if the mishap is high visibility and if so, to assemble the HCAT and brief them on the available mishap details. This first briefing is referred to as the Mishap Response Teleconference, or MRT. Following the MRT, the HCAT works on a forward plan for managing the high visibility mishap and prepares the first official external notifications to NASA's stake-holders, including the public.

The second major change was the adoption of a Standing MIIB. After a thorough internal review, the MIIB concept was presented to the White House and approved in late spring of 1995. The Board is comprised of the individuals filling the following federal government positions:

1) U.S. Navy Commander, Naval Safety Center
2) U.S. Air Force Commander, Air Force Flight Test Center
3) U.S. Air Force Commander, Air Force Safety Center (Air Force Chief of Safety)
4) Department of Transportation, National Expert on Aviation Human Factors
5) Federal Aviation Administration, Director of Accident Investigation
6) U.S. Air Force Commander, 14th Air Force
7) NASA Field Center Director (not mission related to the accident)

Once activated, it was envisioned that the Board would be supported by a NASA Task Force. Task Force members would be recommended to the Board Chair by the Associate Administrator

for Space Operations, the NASA Chief Safety Officer, and the NASA Chief Engineer. The number and skills of the individuals providing dedicated support as a Task Force member would ultimately be determined by the mishap scenario and size of the Board with Staff.

The June 1995 letters to the initial interagency members filling the above positions asked for their support and explained the rationale and their duties as follows:

> *NASA believes that planning for a pre-established accident Investigation Board will allow an investigation of an incident involving serious injury, loss of life, or significant public interest to begin within 72 hours of the mishap. It would also eliminate perception issues that accompany a purely internal NASA investigation. This plan has been approved by the Executive Office of the President.*

The Board would use NASA's established support structure of working groups, facilities, and procedures, specified in the contingency action plans, to conduct the investigation. All elements of NASA would respond directly to this Board, providing records, data, and any other administrative or technical support as required by the Board. The responses to NASA's request for a Standing Mishap Interagency Investigation Board were unanimously ones of endorsement of NASA's initiative to establish such a Board and full time support for serving on a Board if the need should ever arise.

Attachment B

HEOMD MISHAP INTERAGENCY INVESTIGATION BOARD DESCRIPTION AND PURPOSE

I . GUIDELINES

In the case of a high-visibility, NASA-related HEOMD mishap the NASA Administrator may activate the independent HEOMD Mishap Interagency Investigation Board (the Board). Board activation is anticipated for events involving serious injury, significant public interest, and other serious mishaps. For mishaps that involve loss of crew or loss of vehicle, a Commission may be formed (See Appendix D). The board will consist of a minimum of seven members, and be supported by HEOMD HQ and technical consultants as required. For an ISS visiting vehicle contingency, the vehicle owner has the primary responsibility for investigation activities. The NASA Administrator may identify a liaison to coordinate with the investigative activities and offer assistance.

2. ACTIVATION

The recommendation for the NASA Administrator to activate this Board would normally be made at either the AA/HEOMD directed mishap response teleconference or as a decision at the Administrator's HCAT meeting and/or teleconference. When recovery of the crew occurs over an extended period of time, such as an orderly evacuation of the ISS, where it may take weeks or months, the Administrator may choose not to immediately activate the Board and delay activation until the crew is safely on Earth.

3. MEMBERSHIP

Board Chair — Appointed by the NASA Administrator
Board Members
1. Commander, Naval Safety Center
2. Commander, Air Force Flight Test Center
3. Commander, Air Force Safety Center and USAF Chief of Safety
4. DOT National Expert on Aviation Human Factors
5. FAA Office of Accident Investigation
6. Commander, 14th Air Force
7. NASA Field Center Director or NASA Program AA (Non-HEOMD or Non-Mission-Related)

4. BOARD SUPPORT

a . Standing Board Support Personnel
(1) Ex-Officio Member: NASA Chief Safety Officer
(2) Executive Secretary: NASA Chief Engineer
(3) Contracts and procurement specialist: Will be designated by the AA for Mission Support

b. Additional Personnel Support. The Board may designate consultants, experts, or other government or non-government individuals to support the Board as necessary. In addition, the Board may substitute a non-NASA person as Executive Secretary at the discretion of the Board Chair.

c. Task Force Team Support. Within 72 hours of activation of the Board, the AA/HEOMD, the Chief S&MA Officer, the NASA Field Center Director or NASA Program AA (Non-HEOMD or Non-Mission-Related), and the NASA Chief Engineer will meet to select and recommend Task Force Team members to the Board Chair. Upon approval by the Board Chair and appointment by the NASA Administrator, the Task Force Team members will convene and meet with the appropriate Working Group Team Leads. The Task Force Team may to the extent that the Board deems appropriate:
(1) Be the formal interface between the Board and the activated working groups.
(2) Monitor, collect, document, and file the reports of the working groups activated to support the accident investigation.
(3) Provide the Board members with requested information and reports from the working groups.
(4) Assist the Board in the preparation of interim and final reports, as required.

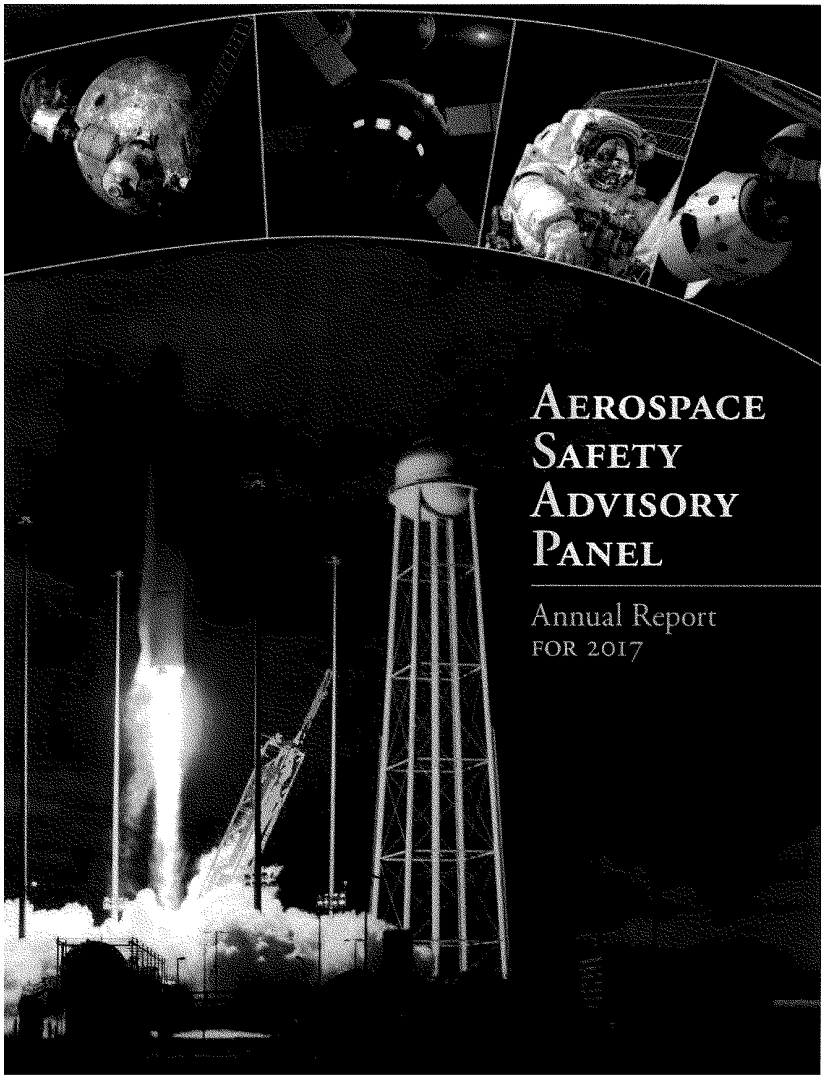
5. BOARD RESPONSIBILITIES
The independent Board will:
a. Conduct activities in accordance with the policies and procedures adopted by the Board.
b. Schedule Board activities, interim Board reports, and submission of the final Board report as the Board deems appropriate.
c. Determine the facts, as well as the root causes, contributing factors, significant observations and recommend preventive and other appropriate actions to preclude recurrence of a similar mishap. The investigation will not be conducted or used to determine questions of culpability, legal liability, or disciplinary action.
d. Use the established NASA support structure of working groups, NASA Field Center support, and supporting facilities to conduct the investigation, as the Board deems appropriate. The Board may use non-NASA support as it deems appropriate.
e. Activate the working groups appropriate to the mishap.
f. Obtain and analyze whatever facts, evidence, and opinions it considers relevant by relying upon reports of studies, findings, recommendations, and other actions by NASA officials and contractors or by conducting inquiries, hearings, tests, and other actions the Board deems appropriate. In so doing, the Board may take testimony and receive statements from witnesses. All elements of NASA will cooperate fully with the Board and provide any records, data, and other administrative or technical support and services that may be requested.
g. Impound property, equipment, and records to the extent that the Board considers necessary.
h. Release mishap information and mishap investigation reports as the Board deems appropriate.

i. Develop recommendations for preventive and other appropriate actions. A finding may warrant one or more recommendations, or it may stand alone.
j. Provide a final written report at such time and in such manner as the Board deems appropriate, which, upon its completion, will be immediately released to the public.

Appendix II

Additional Material for the Record

REPORT SUBMITTED BY DR. PATRICIA SANDERS



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

January 31, 2018

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

Dear Mr. Lightfoot:

Pursuant to Section 1906(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 where observers of NASA operations and decision-making, the notices with NASA management, employees, and contractors and the Panel members' own experiences.

It is view of 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 remain focus on program discipline to maintain a sense of urgency while not giving in to schedule pressure, and to continue with program plans without engineering, demonstration, or schedule pressure. 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 consistency of purpose as NASA is on the verge of realizing the results of years of work and immense 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 reversing or commitment negatively impact 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 anticipate every risk. We panels closely over the potential for damage from micrometeroids and orbital debris has become enough and is a major issue in every program. The United States government should seriously consider expanding its efforts to lead in developing international oversight to reduce debris generation and the hazards posed by existing debris.

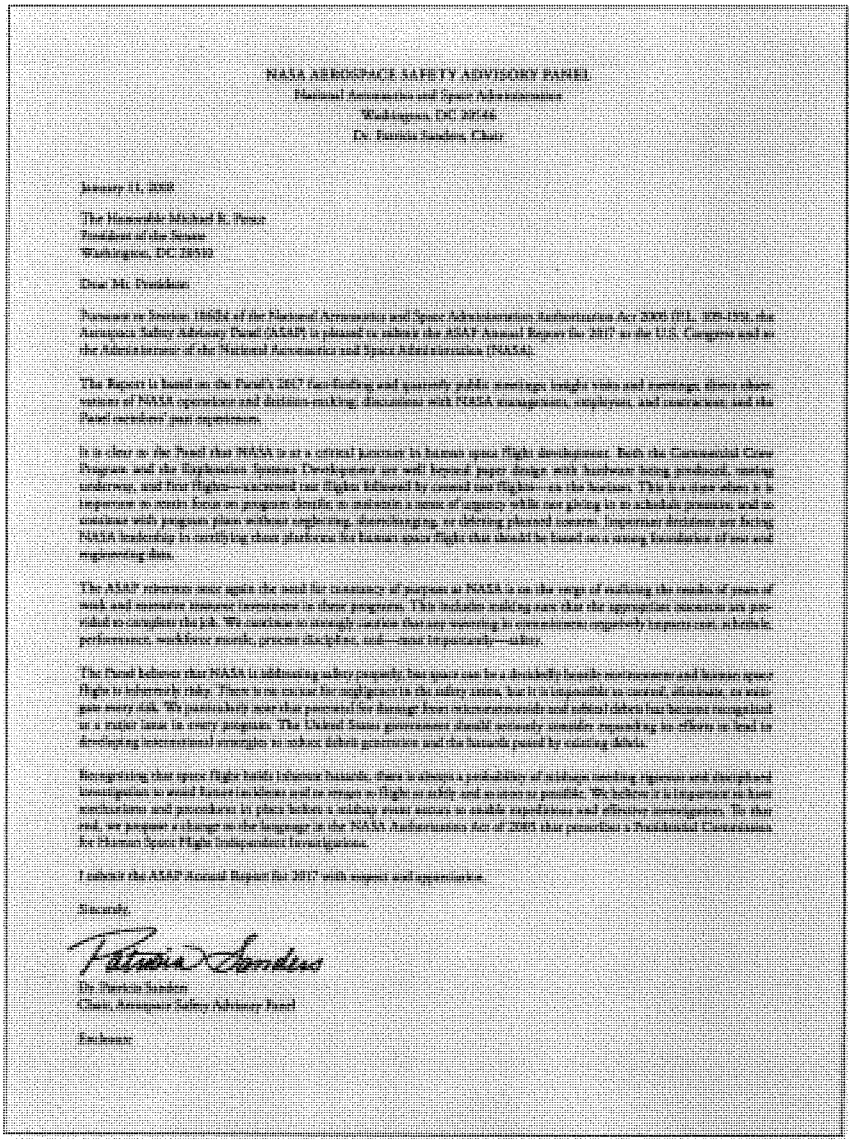
Recognizing that space flight holds inherent hazards, there is always a probability of mishaps causing injuries and fatalities. Investigations to avoid future incidents and to ensure in flight as safely and as soon as possible. We believe it is important to have mechanisms and procedures in place before a mishap occurs to enable expeditious and effective investigations. 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



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

January 11, 2008

The Honorable Michael B. Peace
President of the Senate
Washington, DC 20510

Dear Mr. President:

Pursuant to Section 1302(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 2007 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 2007 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' own 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 remain focus on program details, to maintain a sense of urgency while not giving in to schedule pressure, and to continue with program plans without lengthening, shortchanging, or altering 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 continuity of purpose as NASA is on the verge of realizing the results of years of work and extensive financial 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 warning or 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 anticipate every risk. We particularly note the potential for damage from micrometeroids 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.

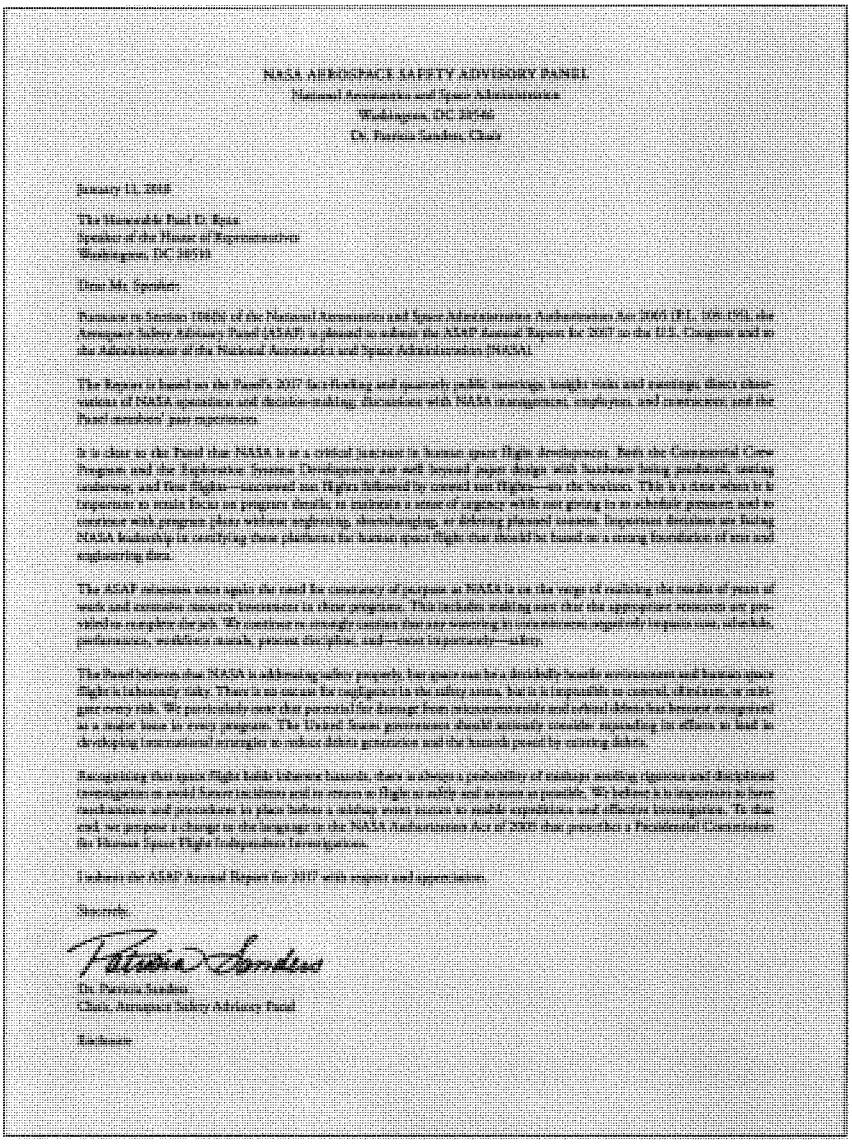
Recognizing that space flight holds inherent hazards, there is always a probability of mishaps causing injuries and disciplined investigations to avoid future incidents and to ensure flight safety are as open as possible. We believe it is important to have mechanisms and procedures in place before a mishap occurs to enable expeditious and efficient investigations. To that end, we propose a change in 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 2007 with respect and appreciation.

Sincerely,

Dr. Patricia Sanders
Chair, Aerospace Safety Advisory Panel

Enclosure



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

January 11, 2018

The Honorable Paul D. Ryan
Speaker of the House of Representatives
Washington, DC 20515

Dear Mr. Speaker:

Pursuant to Section 1006(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 in-briefing 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' own 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 sacrificing, downchanging, or deleting planned content. Important decisions are facing NASA leadership in specifying these platforms for human space flight that should be based on a strong foundation of test and engineering data.

The ASAP remains wary about the need for consistency 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 core mission support—whether it be 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, otherwise, to mitigate every risk. We particularly note that personnel risk damage from micrometeoroids and orbital debris has become recognized as a major issue in every program. The United States government should actively 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 ensure as flight as safely and as soon as possible. We believe it is important to have mechanisms and procedures in place before a mishap occurs to enable expeditious and effective investigations. To this 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 endorse the ASAP Annual Report for 2017 with respect and appreciation.

Sincerely,

Dr. Patricia Sanders
Chair, Aerospace Safety Advisory Panel

Enclosure

Contents

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Preface

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

This report highlights the issues and concerns that were identified or raised by the Panel during its activities over the past year. The Panel's open recommendations are summarized in Appendix 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 Appropriations	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.

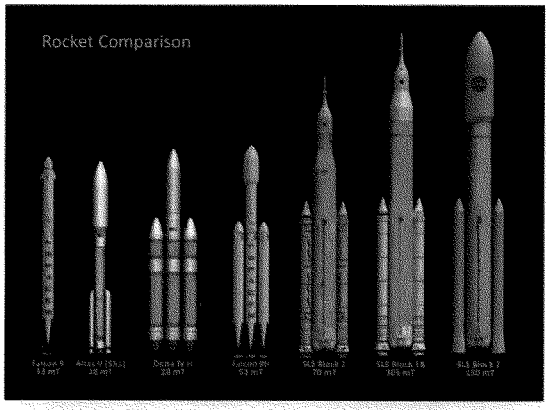


FIGURE 2. Comparison above illustrates significant size of ESD rockets. Hardware of this scale is always a technical and safety challenge.

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

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.

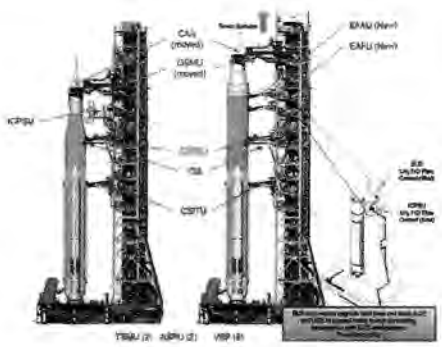


FIGURE 3. Modification of MLP: 13 meters = Big Changes. The items shown in red are major pieces of the MLP that must be removed, altered, or added.

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.

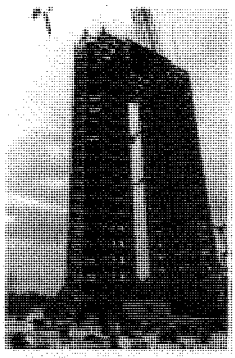


FIGURE 4. LH2 Tank Test Stand

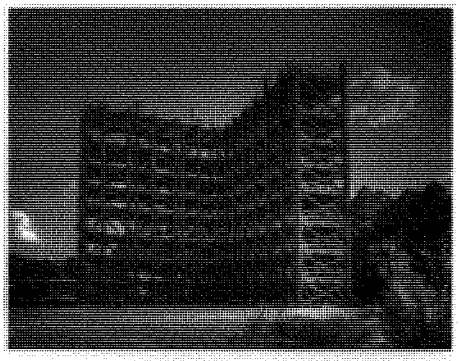


FIGURE 5. LOX Tank Test Stand

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.

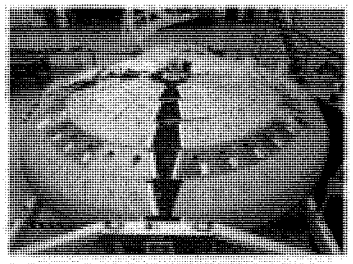


FIGURE 6. Avcoat Block Heat Shield Installation Underway

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 Mar. 2017)
Soyuz 58	March 2018
Soyuz 59	August 2018
Boeing Orbital Flight Test (No Crew)	August 2018
Boeing Crewed Test Flight	November 2018
Soyuz 60	November 2018
SpaceX DM-1	December 2018
SpaceX DM-2	February 2019
Boeing PCM 1	May 2019
Soyuz 61	February 2019
Soyuz 62	August 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

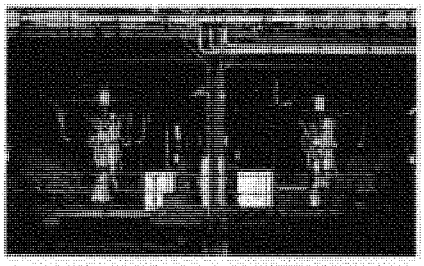


FIGURE 7. SpaceX's Merlin 1D Full Thrust Testing

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.

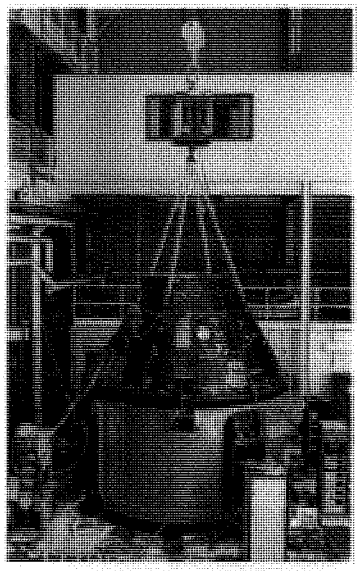


FIGURE 8. Boeing Structural Test Article

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).

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

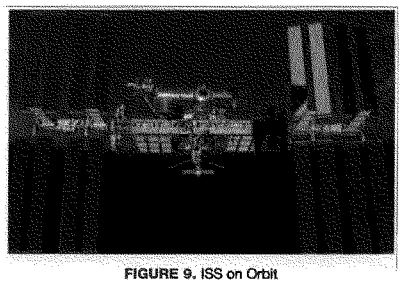


FIGURE 9. ISS on Orbit

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

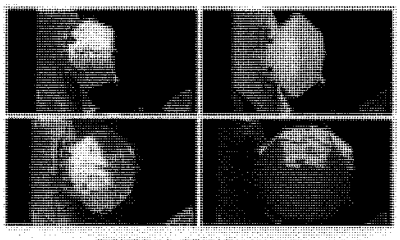


FIGURE 10. BEAM Deployment

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

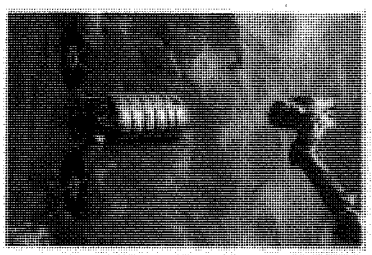


FIGURE 11: Cygnus Approaches Canadarm2

FIGURE 12: Dragon Berthed to ISS

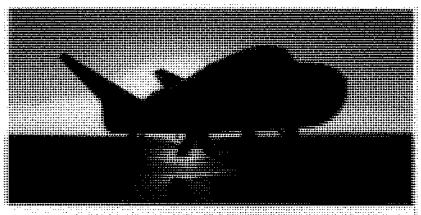


FIGURE 13: Dream Chaser on Armstrong Runway at Dawn

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

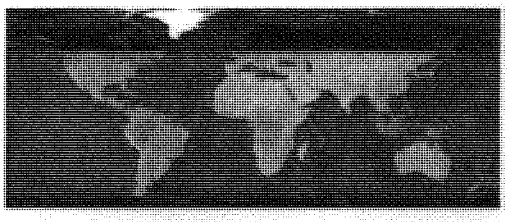


Figure 14. Area within which existing ISS debris has potential to impact

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.

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).

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 cis-lunar 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.

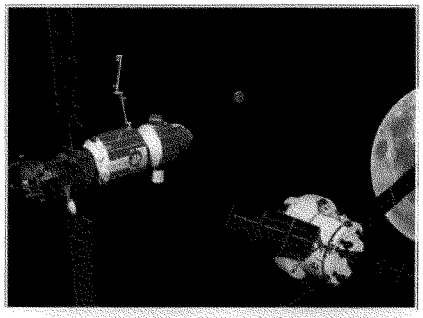


FIGURE 15. Deep Space Gateway Concept

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.

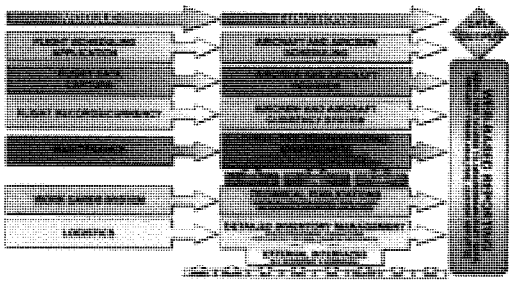


FIGURE 17. Different NAMIS software modules and their functions, as well as interfaces with external systems.

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.

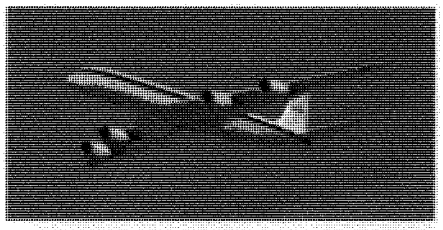


FIGURE 18. Armstrong Flight Research Center's highly-modified DC-8 Airborne Science Laboratory

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

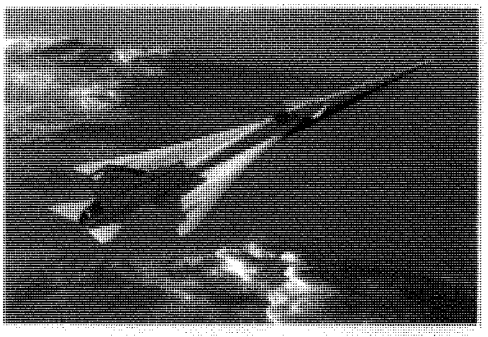


FIGURE 18. NASA Commercial Supersonic Technology Demonstrator

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 inrends to use its new, comprehensive framework to reduce risk across the enterprise.

VIII. Summary

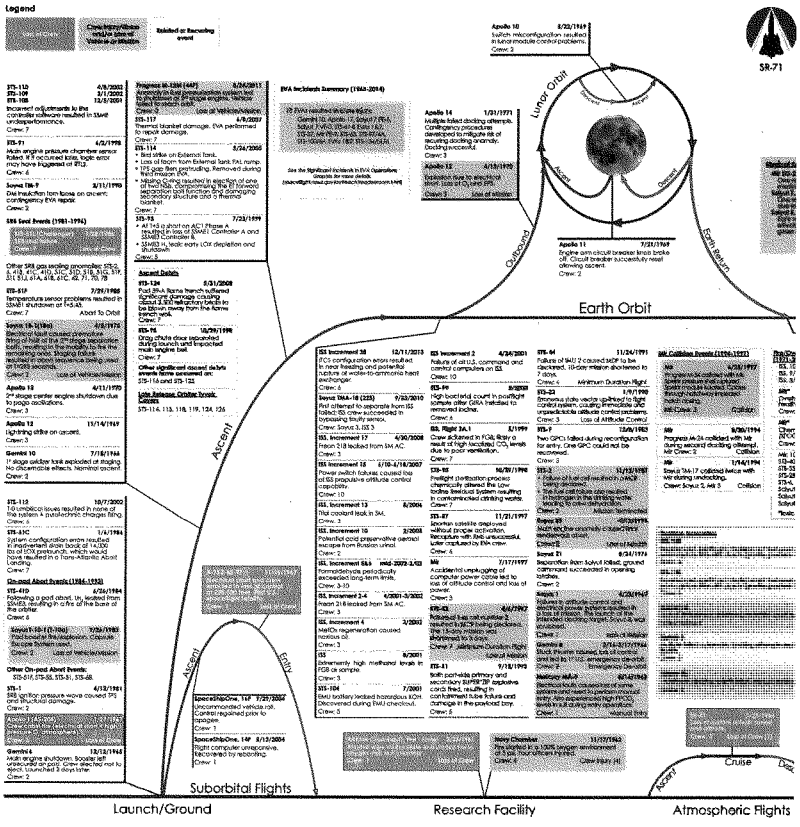
Ten topic areas, highlighted in this report, are summarized in the following table. They have been broken out to focus attention on individual issues that the Panel feels are worthy of note.

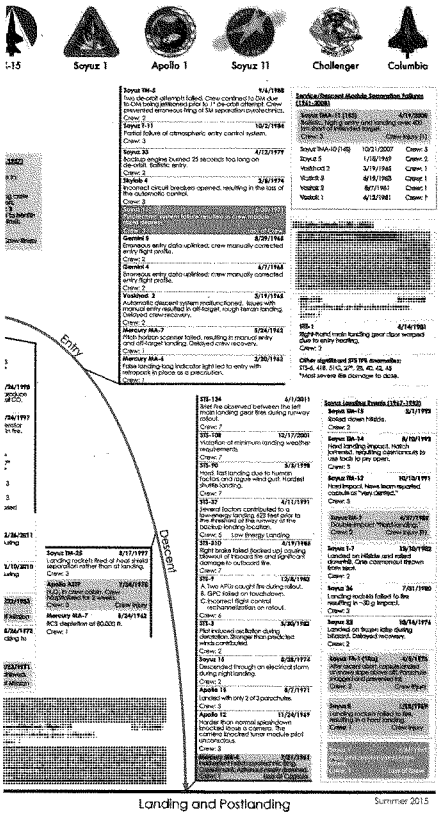
Topics	2017 Assessment
Impact of Continuing Resolution Funding	The Panel continues to be concerned with the continued use of partial year CRs, which add complexity and uncertainty to program management and execution, and detract from the requisite focus on safety and mission assurance.
Micrometeoroids 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





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://spaceflightinfo.nasa.gov/civilreadyhsreadersroom.html) for the latest version of the Significant Incidents and Close Calls in Human Spaceflight chart.

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 Space-ShipTwo 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.

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

SAIC


Aerospace Safety Advisory Panel

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.

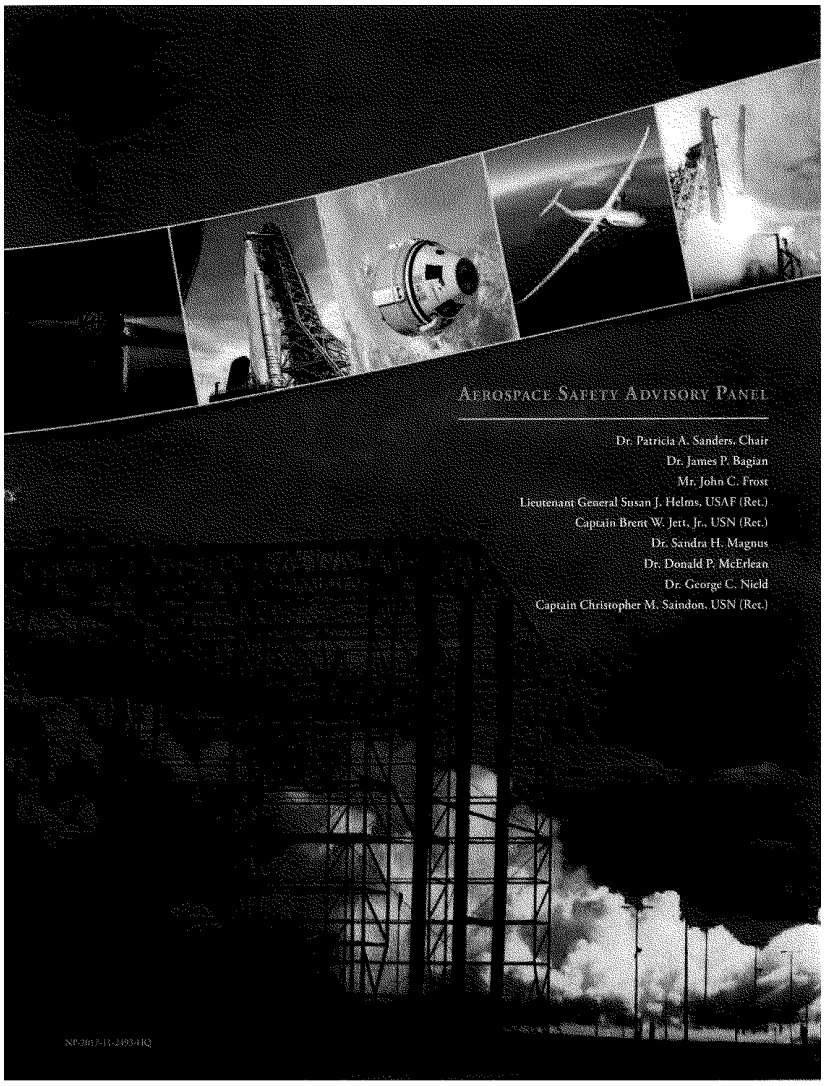
Appendix C

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.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