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Statement of
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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 reliance 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.