STATEMENT OF
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BEFORE THE
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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.

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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.