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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 NASA's progress on our Exploration Systems Development (ESD) programs: the Space Launch System (SLS) heavy-lift launch vehicle, the Orion deep space crew vehicle, and the Exploration Ground Systems (EGS) that provide critical integration and launch infrastructure for these vehicles. The ESD programs are creating a new space transportation capability, the first components of an architecture for human exploration beyond low-Earth orbit (LEO) and into cislunar space. It is in cislunar space where NASA intends to conduct deep space missions to test systems and concepts, paving the way for long-duration human space exploration including missions to the Moon and Mars.

NASA is now in the fabrication and assembly phase of developing SLS, Orion, and EGS, and is focused on bringing these capabilities together to conduct the first Exploration Missions. Exploration Mission-1 (EM-1) is the first integrated test of these new transportation systems. Launching atop SLS, an uncrewed Orion spacecraft will travel into space for up to a 25-day journey beyond the Moon and back to Earth. EM-1 is a test flight, but will also include a payload of several CubeSats that will be deployed to perform a variety of scientific investigations, such as to analyze the presence of water and ice on the Moon, visit and examine a near-Earth asteroid, and detect and measure radiation levels. The data that we gather from these CubeSats will be used to better understand our solar system and, in particular, cislunar space. Production is also underway on flight hardware for the first crewed mission, EM-2, which is planned to launch no later than 2023.

Space Launch System

SLS is planned as a national capability and designed as a heavy-lift launch vehicle for transporting humans and cargo to space. It can also be used as a cargo delivery rocket to enable science missions to reach remote destinations faster, though there are tradeoffs that should be considered when comparing to commercially available vehicles, such as cost and performance. SLS is intended to launch astronauts in the Orion spacecraft on missions to cislunar space. In future updates, it will have the highest-ever payload mass and volume capability, and enough energy to dramatically reduce travel times to deep space destinations. This will enable larger payloads beyond LEO.

SLS capabilities are planned to evolve using a block upgrade approach. SLS Block 1 will have the capability to carry over 70 metric tons to LEO and nearly 30 metric tons toward the Moon, which for the first flight will be used to launch the Orion capsule. The next evolution of the SLS, Block 1B,

incorporates a new upper stage, the Exploration Upper Stage (EUS), now under development, along with updates to associated adaptors. With these planned updates, Block 1B will improve vehicle lift performance to over 105 metric tons to LEO and 40 metric tons to cislunar space, and enable an increase in payload diameter from 5 meters to 7.5 meters and total payload volume from 255 cubic meters to over 900 cubic meters, all of which are capabilities that could help enable deep space exploration.

SLS leverages over a half-century of experience with launch vehicles, including Saturn and Space Shuttle, along with advancements in technology since that time, including model-based engineering, additive manufacturing, high-fidelity computational fluid dynamics capabilities, new composite materials and production techniques, and large-scale self-reaction friction stir welding. Additionally, initial flight units use components already owned from the Space Shuttle, such as RS-25 engines and boosters. More efficient methods are under development for manufacturing these components, including new NASA investment in expendable RS-25 engines for the SLS Core Stage with the goal of achieving a lower per-unit cost than the original reusable RS-25s used as the Space Shuttle Main Engines. The Agency continues to identify affordability strategies for missions beyond EM-2. Reducing overall costs of the systems will be critical to achieving a successful and sustainable exploration capability.

In FY 2017, SLS continued to progress towards EM-1, and concurrently, develop the Block 1B vehicle. The Program completed the Orion Stage Adapter (OSA)/Interim Cryogenic Propulsion Stage (ICPS)/Launch Vehicle Stage Adapter (LVSA) integrated structural test qualification phase ahead of schedule. The ICPS has been delivered to the Kennedy Space Center in Florida and is now in storage at the Space Station Processing Facility. In February 2017, an F-3 tornado caused significant damage on the site of the Michoud Assembly Facility (MAF) in Louisiana where the Core Stage is manufactured. Thanks to the extraordinary work of personnel at MAF and the swift passage of an emergency supplemental bill that will support damage repairs, production at MAF was quickly restored, enabling the Program to complete a major milestone with the completion of major welding of the five large Core Stage sections (forward section, liquid oxygen tank, intertank, liquid hydrogen tank, and engine section) in the Vertical Assembly Center (VAC). The VAC is the largest of the six new large welding tools at MAF; together, these tools represent a major advance in manufacturing technology that reduces the number of tools and touch labor by 50 percent compared to Space Shuttle External Tank production.

The SLS program also completed the Core Stage Pathfinder build. The Pathfinder, a full-sized 212 foot long, 228,000 pound replica of the SLS Core Stage, will be used to test shipping and handling equipment and procedures at the Stennis Space Center (SSC) in Mississippi (where the Core Stage will be test fired on the B-2 test stand) and Kennedy Space Center (KSC). For Core Stage engines, NASA engineers closed a summer of successful hot fire testing for flight controllers on the RS-25 engines that will help power the SLS. The 500-second hot fire of a RS-25 engine flight controller unit on the A-1 Test Stand at SSC marks the completion of the engine adaptation testing to certify the former Space Shuttle engines for use in the more challenging SLS environment. The test series also certified the new engine controllers and new control software for EM-1. All EM-1 Core Stage engines have now completed their single-engine test sequences and are being packaged for delivery to MAF for integration into the Core Stage in FY 2018.

Finally, the SLS Program began manufacturing on a number of components for the EM-2 mission, including completing major welding of the EM-2 core stage engine section in FY 2017 and completion of the EUS Preliminary Design Review (PDR), which validates progress to critical design and fabrication.

In FY 2018, Core Stage integration and outfitting (including installation of the four RS-25 engines) will continue at MAF, though challenges remain to completing production of the Core Stage and delivery to the Stennis Space Center in Mississippi in December 2018 for the Green Run test sequence. FY 2018 will also see a series of EM-1 flight hardware deliveries to EGS at KSC, starting this month with the

hand-over of the ICPS, followed by the OSA and LVSA. The EM-1 Booster segments will arrive at KSC beginning final assembly with the aft and forward skirts. SLS will prepare for the EM-1 Design Certification Review planned for early 2019, conduct the EM-2 Critical Design Review (CDR), and begin fabrication of components for EM-3 and beyond.

Orion

NASA's Orion spacecraft builds upon more than 50 years of spaceflight research and development. Its design is meant to be able to carry crew to space, provide emergency abort capability, sustain crew during space travel, and provide safe reentry at the high-return velocities typically needed for deep space missions. Orion is designed to support human exploration missions to deep space with a crew of four for periods of 21 days. However, with modifications and the support of other new deep space elements, most of the Orion capsule systems could be capable of operations in deep space for periods of time up to 1,000 days. Additionally, the Orion systems are designed to operate in a contingency mode to augment life support systems in other space transport systems.

Orion's crew module (CM), spacecraft adapter, and launch abort system (LAS) incorporate numerous technology advancements and innovations. Orion's LAS can activate within milliseconds to carry the crew from harm's way and position the module for a safe landing. The spacecraft's propulsion, thermal protection, avionics, and life support systems will enable extended duration missions beyond Earth orbit and into deep space. Its modular design will be capable of integrating additional new technical innovations as they become available.

The European Space Agency (ESA) is providing the European Service Module (ESM) for Orion, including structural and propulsion qualification test articles and the flight articles for EM-1 and the crewed EM-2 flight. ESA is providing this ESM hardware in lieu of other contributions, as part of their barter agreement with NASA for ESA utilization of the International Space Station (ISS). ESM qualification and structural hardware is currently undergoing testing at the White Sands Test Facility in New Mexico and Colorado, while the EM-1 flight article is in production today at the Airbus Space and Defense facility in Bremen, Germany, for scheduled delivery in 2018.

Orion's design, development, and testing (including flight tests) schedule is intended to have the spacecraft ready to carry crew to the area around the Moon no later than 2023. Any future flights of SLS and the Orion spacecraft into cislunar space will be intended to extend NASA's capability for human deep space exploration operations, and demonstrate an evolving set of capabilities in cislunar space to reduce the overall risk of longer duration missions.

In FY 2017, Orion Program structural testing made significant progress, including the delivery of the ESM Structural Test Article (STA) from NASA's Plum Brook Station in Sandusky, Ohio to KSC, then to Denver, Colorado, to support integrated Crew Module (CM), LAS, and ESM STA testing in FY 2018. The Program completed a successful hot fire test of the LAS attitude control motor (HT-11) in April 2017 and a successful test of the LAS abort qualification motor 1 in June 2017. ESA's ESM Propulsion Qualification Module was installed at NASA's White Sands Test Facility in February, and the first hot fire test of the Reaction Control System thrusters for Orion's ESM was conducted. The Program has conducted 17 full-scale development airdrop tests on the Orion parachutes at the U.S. Army Proving Ground in Yuma, Arizona, and is half way through the qualification program of 8 tests. Engineers at the Space Power Facility at Plum Brook station in Sandusky, Ohio, conducted acoustic testing on the ogive panels. The ogive panels protect Orion's crew module from harsh acoustic conditions at launch and in case of an abort. The EM-1 CM and Crew Module Adapter (CMA) production at the KSC Neil Armstrong Operations and Checkout Building has made significant progress; both the CM and the CMA

have completed initial power on. During the initial power-on tests, engineers and technicians connected the vehicle management computers to Orion's power and data units to ensure the systems communicated precisely with one another to accurately route power and functional commands throughout the spacecraft for the duration of a deep space exploration mission. Steady progress is also being made on the EM-1 ESM being manufactured in Bremen, Germany. NASA and a Department of Defense team tested Orion exit procedures in a variety of scenarios in July in the waters off the coast of Galveston, Texas.

In addition, the Orion Program began manufacturing of components for the EM-2 mission, including the crew module forward and aft bulkheads, the crew module cone panel, solar cells, and EM-2 motors.

In FY 2018, Orion will continue qualification testing of Orion systems for the first crewed flight. As part of this qualification work, NASA is planning to accelerate the ascent abort-2 test (AA-2) into 2019, ahead of an updated EM-1 launch date. Structural work is already underway on Orion EM-2 flight hardware production, and this will continue in FY 2018. For EM-1, the ESM is scheduled to be delivered to the Operations and Checkout Building at KSC for integration with the CM in April 2018 and the start of integrated thermal vacuum testing in November 2018, though challenges remain to this schedule, including timely delivery of necessary components to support the ESA hardware integration schedule and shipment to KSC.

Exploration Ground Systems

The objective of EGS is to prepare KSC to process and launch the SLS and Orion. To achieve this transformation, NASA is developing new ground systems while refurbishing and upgrading infrastructure and facilities to meet tomorrow's demands. This modernization effort is designed to maintain maximum flexibility in order to also accommodate a multitude of other potential Government and commercial customers. Drawing on five decades of excellence in processing and launch, KSC continues to work toward serving as a multi-user spaceport as was envisioned post Space Shuttle retirement.

The EGS program enables integration, processing, and launch of SLS and Orion, and the program is making the required facility and ground support equipment modifications at KSC to enable assembly, test, launch, and recovery of the SLS and Orion flight elements. EGS is also modernizing communication and control systems to support these activities. Upon completion, the KSC launch site will be able to provide a more flexible, affordable, and responsive launch capability for SLS and Orion when compared to approaches used for the Space Shuttle.

In FY 2017, EGS completed Vehicle Assembly Building (VAB) platform installation and outfitting. EGS' renovation of Launch Pad 39B is progressing well and includes upgrades and modifications to the flame trench, environmental control system, and a new flame deflector. EGS successfully tested Crawler-Transporter 2 (CT-2) upgrades; CT-2 upgrades included new generators, gear assemblies, jacking, equalizing and leveling hydraulic cylinders, roller bearings and brakes. The Program is progressing with Multi-Payload Processing Facility (MPPF) Verification and Validation; this facility will be used for offline processing and fueling of the Orion spacecraft and service module stack before launch. As of September 2017, the EGS Program had completed the installation of five sets of umbilicals/attach points on the Mobile Launcher (Orion Service Module Umbilical, Core Stage Intertank Umbilical, Core Stage Forward Skirt Umbilical, Vehicle Support Posts, Aft Skirt Electrical and Pneumatic Umbilicals), completing more than 70 percent of the umbilical and launch accessory deliveries to the Mobile Launcher from the Launch Equipment Test Facility. The first major integrated operation at Launch Pad 39B at KSC began in September 2017 with the initial test filling of the Liquid Oxygen (LO2) storage tank, a giant sphere that can hold about 900,000 gallons of LO2 and maintain the propellant at cryogenic temperatures of -297 degrees Fahrenheit. Hardware delivered to EGS this year included left-hand

forward skirt for SLS solid rocket boosters, service platforms for SLS booster engines, and the ICPS. Damage to EGS systems during Hurricane Irma was minimal (limited to some minor damage to the MPPF and some water intrusion on the Mobile Launcher, none of which will significantly impact EM-1 preparations), thanks to the diligence of EGS personnel to "safe" systems ahead of the storm.

In FY 2018, once the program has completed the system verification and validation phase, it will begin the operations and integration phase in preparation for Multi-Element verification and validation for the Mobile Launcher, Pad, and VAB. Spacecraft offline processing will begin in the fourth quarter of 2018.

Exploration Mission-1

The preponderance of SLS, Orion, and EGS development and production content is making sustained progress toward EM-1, and work is underway to prepare for the first flight of crew on EM-2 and subsequent exploration missions. While progress on these programs has been substantial, NASA, its contractors, and international partners have faced challenges with first-time design and assembly. This has adversely affected the schedule for the EM-1 test flight, and as a result, the Agency has rescheduled program planning of EM-1 to reflect completion of work required to prepare for flight. While NASA's review shows an EM-1 launch date of June 2020 is possible, the Agency is managing to December 2019. NASA is taking additional steps to reduce schedule risks known and unknown, and protect for the earlier launch date. NASA's ability to meet the Agency's Baseline Commitment for EM-1 cost, which includes SLS and ground systems, currently remains within original targets. Orion is included in NASA's EM-2 Agency Baseline Commitment.

NASA has made significant progress in addressing some of these development issues. For instance, the SLS program has resolved the VAC weld strength issues and all VAC assembly welding for EM-1 is now complete. Additionally, NASA continues to make progress on key elements. All EM-1 booster separation motors are cast and finalized, and the engine controller qualification testing has been completed. The EM-1 CM and CMA production at the Operations and Checkout Building is making good progress; both the CM and the CMA have completed initial power on. ESM coordination on assembly, integration, and testing is improving, and NASA has increased involvement in resolving domestic and international vendor technical and schedule performance issues. The Interim Cryogenic Propulsion Stage has been delivered to EGS. At the Kennedy Space Center, VAB platform installation is complete. Pad 39B development is progressing well, and five sets of umbilicals/attach points have been installed on the Mobile Launcher as of September 2017. Finally, NASA is making progress with ongoing issues associated with spacecraft command and control software.

Conclusion

The Agency has developed an approach to expand the distance and duration of human space exploration, building off the exploration happening today on the ISS. The SLS, Orion, and EGS programs are developing systems intended to provide transportation capabilities for human space exploration beyond low-earth orbit.

While NASA continues to shape this exploration architecture, the objective is to extend human presence deeper into the solar system through a sustainable human and robotic spaceflight program. On October 5, 2017, the National Space Council finalized a recommendation to the President to alter existing policy for NASA's human exploration program to focus on "an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system" and that such a program would "lead the return of humans to the Moon for long-term exploration and utilization,

followed by human missions to Mars and other destinations." NASA is working with the Executive Office of the President on further policy and budgets to support this directive.

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