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Statement of
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Subcommittee on Space, Science, and Competitiveness
Committee on Commerce, Science, and Transportation
United States Senate

Mr. Chairman and Members of the Subcommittee, I am pleased to have this opportunity to discuss NASA's human space exploration efforts, which will expand humanity's presence in the solar system in an evolving sequence.

Our human space exploration efforts are part of a balanced portfolio of programs being undertaken by the Agency that enable the U.S. to be the world leader in aerospace research, development, and exploration. We are planning for significantly accelerated Aeronautics Research that will support a vigorous flight demonstration program to validate technologies to dramatically improve the aircraft of the future. In Science, the Juno Spacecraft entered Jovian orbit just last week. Starting in late 2016, the Cassini spacecraft will begin its dramatic "Grand Finale" orbits of Saturn. The Solar Probe Plus (SPP), Transiting Exoplanet Survey Satellite (TESS), the Interior Exploration using Seismic Investigations Geodesy and Heat Transport (InSight) mission to Mars, and the James Webb Space Telescope (JWST) are all on track to launch over the next two years, and a new Mars rover is in development for a 2020 launch on its way to join the spectacular Curiosity rover now exploring the planet; InSight and Mars 2020 will join the five NASA-led missions already at Mars. NASA's Earth Science missions continue to advance our knowledge of how our home planet functions as a system. In the area of Space Technology, we are conducting rapid development and incorporation of transformative space technologies, such as solar electric propulsion and optical communication, to enable NASA's future missions and address aerospace industry challenges.

NASA's Journey to Mars is guided by the strategic direction this Committee incorporated into the NASA Authorization Act of 2010. The Agency is well positioned to continue on this long-term mission, and we look forward to maintaining this constancy of purpose by earning the continued support of future Administrations and Congresses. Beginning with the Earth-Reliant phase in low Earth orbit (LEO) aboard the International Space Station (ISS), we will then move into the Proving-Ground phase deeper into cislunar space around the Moon with the Orion crew vehicle and Space Launch System (SLS) heavy-lift rocket (as well as the ground systems that support them), and future deep-space habitation capability. Once we have developed the required technologies and practiced the techniques necessary in these environments, we will move on into the Earth-Independent phase, in which we will send our crews on missions of exploration to visit a multi-ton asteroid boulder we have brought to cislunar space and then into deep space, and on to Mars in the 2030s. NASA, in cooperation with its industry and international partners, has made significant progress in pushing the boundaries of human spaceflight, and we appreciate the Committee's support of our efforts. The challenges associated with the Journey to Mars will require continued contributions from all parties and require us to work together.

ISS and Commercial Transportation: Research and Economic Development in LEO

The ISS supports research across a diverse array of disciplines, including high-energy particle physics, Earth remote sensing and geophysics, molecular and cellular biotechnology, human physiology (including bone and muscle research), radiation, plant propagation and cultivation, combustion, fluids, materials science, and biology. In addition, the ISS is an invaluable platform for research and development for next-generation technologies, not only in areas directly related to NASA's exploration efforts, but also in fields that have numerous terrestrial and commercial LEO applications. As of May of this year, the estimated number of investigations conducted aboard ISS was 2,184 (this includes 103 new investigations in Expeditions 47/48), with over 800 investigators represented, and over 1,200 publications of scientific results. Through Expedition 42, over 90 countries and areas had participated in ISS research and education activities.

The ISS – which has been home to a continuous human presence on orbit for almost 16 years – is humanity's only long-duration flight analog for future human deep-space missions. The ISS is vital to NASA's mission to extend human presence into the solar system. In order to prepare for human expeditions into deep space, we must first use the unique environment of ISS to conduct the research and technology demonstrations necessary to keep our crews safe and productive on long-duration spaceflights. NASA is planning to dedicate the equivalent of four research racks on ISS to test exploration-class environmental and life support hardware needed for deep space missions. NASA's Human Research Program continues to develop biomedical science, technologies, countermeasures, diagnostics, and design tools to keep crews safe and productive on long-duration space missions. The progress in science and technology driven by this research could have broad impacts on Earth as it advances our ability to support long-duration human exploration.

This past March, NASA astronaut Scott Kelly and cosmonaut Mikhail Kornienko returned from their year in space aboard ISS. They conducted investigations in areas known to be important to safe and productive long-duration spaceflight, including: functional behavioral health, visual impairment, metabolic and nutritional health, physical performance, microbiology, and human factors. Researchers expect data from the mission to inform our understanding of biomedical, performance, and behavioral changes and challenges astronauts will face when they embark on longer-duration missions. Data from the expedition will be used to find ways to further reduce the risks on all long-duration deep space missions.

Under the auspices of the ISS National Laboratory, managed by the Center for the Advancement of Science In Space (CASIS), NASA is encouraging broader use of the ISS by non-traditional companies and other Government agencies. Use of the ISS as a National Laboratory has increased significantly since FY 2012, which was the first full year of operations by CASIS, and users include the commercial sector, other Government agencies, and academic institutions. The ISS National Laboratory has reached full capacity for allocated crew time for research and will help establish and test the market for research and technology development in LEO beyond the needs of NASA.

Under the Commercial Resupply Services (CRS) contracts our two commercial cargo partners, Space Exploration Technologies (SpaceX) and Orbital ATK, have demonstrated not only the ability to provide cargo deliveries to ISS, but also the flexibility to recover effectively from mishaps. Both companies have worked closely with NASA to understand the anomalies they experienced over the last two years. In developing the launch vehicles for their cargo spacecraft, SpaceX and Orbital ATK have also helped to bring a significant portion of the commercial satellite launch market back to the U.S., and helped to significantly lower launch costs. This January, through CRS-2, NASA contracted with SpaceX, Orbital

ATK, and Sierra Nevada Corporation to ensure that critical science, research, and technology demonstrations will be delivered to the ISS from 2019 through 2024.

Our commercial crew partners, SpaceX and the Boeing Company, are developing the Crew Dragon and CST-100 Starliner spacecraft, respectively. The work, being done under two Federal Acquisition Regulation (FAR)-based, fixed-price Commercial Crew Transportation Capability (CCtCap) contracts, is currently expected to result in flight certification for SpaceX in 2017, and for Boeing in 2018. In 2015, NASA ordered the initial post-certification missions, and in 2016, milestone completion and work are progressing well. U.S. commercial crew capabilities will enable the Station crew to be expanded from six to seven astronauts and cosmonauts, resulting in a doubling of on-orbit research time to almost 80 hours per week. This is because the additional work time equivalent of the seventh crew member will be dedicated almost exclusively to conducting experiments, rather than on Station operations and maintenance.

As you know, NASA plans to continue ISS operations and utilization through at least 2024. The Agency expects to support continued research needs in LEO after the end of the ISS program. The Agency will work with industry, academia, and other government agencies through consortia and other means to establish long-term LEO demand investment and research/technology development. Encouraging the emergence of economic activity in LEO has significant implications – and offers significant opportunities – for the Nation. Enabling the effective use of this unique environment will call upon expertise resident across the U.S. Government in areas including commerce, science, and transportation. NASA and other relevant agencies are working in a unified manner towards the important National objective of realizing the economic potential of this new frontier.

Orion and SLS: Traveling Beyond LEO

As we extend further into cislunar space, from LEO out into the Proving Ground, we will employ new deep space exploration systems, comprising the heavy-lift SLS, Orion crew vehicle, the Exploration Ground Systems (EGS) that support them, new deep space habitation capabilities and new commercial and international partnership opportunities. We also have proposed increased investment in exploration research and development and space technologies, which are critical for making future missions safer, more reliable, and more affordable.

NASA's initial deep-space mission, Exploration Mission-1 (EM-1), is on track to launch to a distant retrograde orbit in the Proving Ground around the Moon in 2018. The three-week flight without crew will provide the program with data to validate spacecraft design and operations. In 2015, the Agency baselined the Orion program plan, establishing an Agency baseline commitment for Orion that supports a launch readiness date for the first crewed flight on EM-2 no later than 2023. Current planning continues to support an EM-2 launch in 2021. In the initial phase of our Proving Ground operations, NASA will use this region of space to test and demonstrate flight and mission operations and staging of human-rated vehicles farther from Earth than ever before. These crewed Orion missions launched on the SLS in the 2020s will establish our capability to operate safely and productively in deep space.

Orion, SLS, and EGS provide the foundational components critical to human spaceflight beyond LEO, and the vehicles are being designed to enable multiple deep space missions and destinations rather than being optimized for one particular mission or architecture. The Orion spacecraft includes both a Crew Module and Service Module designed specifically for the rigors of missions far from Earth and outside Earth's protective radiation belts, and a Launch Abort System. Orion alone can support a crew of up to four, with enough internal stowage for 21 days of food, water and air, and its systems are designed to operate for over a year if necessary. The SLS is a heavy-lift, exploration-class launch vehicle that will transport Orion, as well as cargo and other systems, with a range of lift capabilities from 70 metric tons to LEO, evolving to up to 130 metric tons. Studies have shown the benefit of such a large, single-flight lift capability. EGS launch infrastructure design, development, and refurbishment at Kennedy Space Center (KSC) will support SLS and Orion.

Subsequent missions in the Proving Ground will target challenges and strategic knowledge gaps while helping develop the core capabilities necessary to expand human activity farther into deep space. NASA is planning an early SLS and Orion mission to rendezvous with a multi-ton asteroid boulder that will be stationed in lunar orbit using a demonstration of advanced solar-electric propulsion. In this mission, our astronauts will use deep-space Extravehicular Activity (EVA) technologies to select, extract, and contain samples from the multi-ton primordial planetary mass. This Asteroid Redirect Mission (ARM) also provides demonstration of a deflection technique called the enhanced gravity tractor that could be used on potentially hazardous asteroids and help us assess the potential for asteroid resource utilization for both exploration and commercial purposes. In addition, ARM provides a demonstration of advanced solar-electric propulsion to move multi-ton masses, advanced autonomous rendezvous and proximity operations at a microgravity planetary body, complex crew operations in the Proving Ground of lunar orbit, and a power/propulsion bus asset in cislunar space that may be used after this mission. ARM is developing technologies and capabilities necessary for deep space exploration by crews. Moving large objects such as a boulder presents essentially the same technical challenges as moving large cargo vehicles to support long-duration deep space crewed missions.

The NASA-Industry teams building SLS and Orion have made tremendous progress over the last year in building and testing vehicle components. For SLS, core stage production is accelerating at the Michoud Assembly Facility (MAF) in Louisiana. After a delay to correct a structural alignment issue with the weld tool, the largest friction stir weld machine of its kind in the world, the Vertical Assembly Center is now operational and has completed production of the qualification article for the 131-foot-tall liquid hydrogen core stage tank and the first flight article engine section. The giant structural test stands at the Marshall Space Flight Center in Alabama and the B-2 core stage test stand at the Stennis Space Center in Mississippi are nearing completion. In June, SLS conducted the final qualification test of the five-segment solid rocket motor, and while the results are still being analyzed, the early indications are that the booster passed this critical test. The first three EM-1 booster motor segments have been cast and production of the remaining flight motors continues on schedule at the Promontory facility in Utah. Core stage engine testing has continued its success with the first test of a flight engine, and the next engine test series will begin later this month.

For Orion, the EM-1 flight article has entered the assembly phase. The Crew Module primary structure, which is the pressure vessel to hold the crew's atmosphere against the vacuum of space, is at KSC undergoing outfitting and integration after having completed pressure testing. The European Service Module primary structure is undergoing outfitting in Bremen, Germany. The Service Module, which provides propulsion, power, and life support to the Crew Module, is being provided for EM-1 through a partnership agreement with the European Space Agency (ESA). In March 2016, NASA exercised an option for ESA to provide the Service Module for EM-2. ESA recently completed the Critical Design Review (CDR) for the Service Module. While the NASA and ESA teams continue to assess a three-month delay in delivery of the EM-1 Service Module to KSC, the CDR board confirmed that the Service Module design is cleared for manufacturing, and the teams continue to hold for an EM-1 launch in 2018. In addition to the EM-1 flight article, Orion is also conducting extensive ground testing to demonstrate the systems for deep space. Software testing is underway in the Integrated Test Lab in Denver. A dedicated Crew Module structural test article is undergoing manufacturing at MAF. Meanwhile, the European-built Service Module structural test article is undergoing acoustic, vibration, solar array deployment, and thermal tests at Plum Brook Station in Ohio. Water landing tests are underway at NASA Langley Research Center in Virginia, and parachute qualification testing is starting in Arizona. Between the EM-1 flight article assembly and the thorough ground test campaign, Orion is progressing methodically toward the first crewed flight on EM-2.

In Exploration Ground Systems, four of the ten giant platforms in High Bay 3 of the Vehicle Assembly Building have been installed, and the remaining platforms continue to arrive at KSC. Mobile Launcher structural modifications are complete and outfitting is underway, while modifications to the Crawler Transporter are nearly complete. The umbilical systems used to interface the Mobile Launcher with SLS and Orion are also being tested at KSC. Software development and integration continues to be a major focus for all the programs and the exploration enterprise, and the successful validation of Spacecraft Command and Control Software version 3.4 is a major milestone in this effort.

Orion, SLS, and EGS teams are using the latest in systems and manufacturing technology with the intent of developing a safe system capable of extending human presence to cislunar space and to Mars. For example, the Orion team is using time-triggered Ethernet and is taking advantage of the standards for this technology that are used in the automotive industry. Both Orion and SLS are utilizing friction-stir welding (including on large structures, such as the SLS core stage), with the largest friction-stir weld machine in the world. The EGS team has stripped out the old copper cables from Pad 39B and replaced them with the latest in fiber optics. Orion and SLS plans take advantage of advances in additive manufacturing, or “3D printing.” For example, Orion is using this technology to reduce testing costs by printing test versions of flight hardware for use at the Integrated Test Lab in Denver, while SLS is assessing the use of 3D printed parts in future RD-25 engine production. These are just some examples of how NASA’s Exploration Systems are utilizing and advancing the latest in technology.

In developing the Orion, SLS, and EGS, NASA is working toward building a sustainable national capability for the long-term human exploration and pioneering of space. Necessary to this is working to ensure that post-development operating costs will be affordable, and making the necessary investments in technology and other development efforts that will be fundamental for extending human presence to Mars. NASA is keeping each element of the program – Orion, SLS, and EGS – moving at its best possible speed toward the first integrated launch, optimizing each element effort’s schedule while being aware of the overall plan. This is best achieved when each element is allowed to progress on its own schedule, rather than being linked too tightly to the others. When tasks related to EM-1 are completed, the workforce can progress to EM-2. NASA is on a solid path toward an integrated mission and making progress in all three programs every day. With the EM-1 flight just over two years away, and with flight hardware for the mission arriving in about one year, there is real sense of flight preparation cadence building.

Preparing for Mars: Deep Space Habitation Capability and New Technologies

Among the additional capabilities needed for human exploration is long-duration habitation. Validation of this capability in cislunar space will mark our readiness to begin Earth-Independent exploration beyond the Earth-Moon system. An effective habitation capability is comprised of a pressurized volume, and an integrated array of complex systems and components that include a docking capability, environmental control and life support systems, logistics management, radiation mitigation and monitoring, fire safety technologies, and crew health capabilities. NASA’s current strategy is to test these systems and components on the ground and in LEO on ISS, then as an integrated habitation capability for long-duration missions in cislunar space and Mars transit. NASA plans to conduct a long-duration (one-year-plus) mission in cislunar space by the end of the 2020s; this will be critical preparation for crewed missions to Mars. NASA will utilize public-private partnerships to the extent possible for these activities.

One example of habitation technology being tested on ISS is the Bigelow Expandable Activity Module (BEAM), which was launched to ISS on the commercial SpaceX Dragon spacecraft on April 8, 2016, installed on April 16, and expanded on May 28. BEAM will undergo a two-year demonstration period, during which Station crew members and ground-based engineers will gather performance data on the module. While the BEAM demonstration supports a NASA objective to evaluate design options for the development of a long-duration, deep space habitat for human missions beyond Earth orbit, the results of the demonstration will also have applications to private space stations/habitats, which is why Bigelow has co-funded the development of this module.

NASA has been undertaking substantial private-sector and international engagement to define habitation concepts, systems, and implementation approaches to cost-effectively achieve NASA's goals for deep space and enable progress towards LEO commercial space station capabilities. The Agency's Next Space Technologies for Exploration Partnerships (NextSTEP) Broad Agency Announcement (BAA) is an effort to stimulate deep-space capability development across the aerospace industry. NASA issued the original NextSTEP BAA to U.S. industry in late 2014. In March 2015, NASA selected 12 awardees – seven in habitation, three in propulsion, and two in small satellites. NASA has since entered into fixed-price contracts with the selectees. During this same timeframe, NASA has also been conducting architecture studies with our international partners to define the potential areas of contribution from other space agencies, continuing to build on the successes of ISS in exploration.

In April 2016, NASA issued a NextSTEP-2 BAA, an omnibus announcement covering all aspects of basic and applied supporting research and technology for human space exploration and robotic precursor activities. The April release of the NextSTEP-2 BAA included Appendix A: Habitat Systems, which is focused on developing long-duration, deep space habitation concepts, resulting in ground prototype units. This ground-based effort will support development of deep space long-duration habitation concepts and demonstrate systems that NASA will later need to test in the microgravity environment of space. The objective is to identify habitation concepts that can support extensive human spaceflight missions in the Proving Ground and beyond while encouraging application to commercial LEO habitation capabilities. One goal of this public-private approach is to enable the United States to develop the deep space habitation capability at a lower cost than through a cost-plus procurement approach. The Agency plans to select multiple proposals under NextSTEP-2, Appendix A, in the near future, with an estimated period of performance to begin in September 2016 and extend out to about April 2018. NASA intends to integrate functional systems into a prototype habitat for ground testing in 2018.

Our missions into deep space will require the development of an array of new technologies in a variety of areas, including advanced, high-thrust, in-space propulsion, environmental control and life support systems, *in situ* resource utilization (ISRU), and communications. NASA is working to develop and demonstrate highly efficient solar electric propulsion through ARM. The same spacecraft "bus," and extensions of it, could be used in the future to transport large masses of systems and cargo to the vicinity of Mars in advance of the crewed expedition to the planet. Advances in ISRU will one day allow exploration crews to utilize space resources to manufacture fuel and oxidizers for propulsion systems, provide water for human consumption, produce materials for additional radiation shielding, and even serve as the building blocks for additive manufacturing. The Mars Oxygen ISRU Experiment (MOXIE), which will fly on Mars 2020, will verify that ISRU technologies can produce oxygen from the atmosphere of Mars to supply both human breathing needs as well as propellant oxidizer for Mars ascent vehicles. Optical (i.e., laser-based) communication will enable the transfer of data from distant missions back to Earth at much higher rates than are attainable using current radio-frequency communications systems. The Agency is also testing on-board systems to keep crews safe, including fire detection, suppression, and cleanup technologies. In order to better understand fire in space, in June 2016, NASA conducted the Spacecraft Fire Experiment (Saffire-1), which intentionally lit a large-scale fire inside an empty Cygnus cargo vehicle after it left the Station, but before re-entering Earth's atmosphere. Instruments and cameras measured flame growth, oxygen use, heat generated, and more, improving understanding of fire growth in microgravity and safeguarding future space missions.

Ensuring Astronaut Health

The spaceflight environment includes hazards and stressors that are unique and whose effects on humans are not always well understood, due largely to the limited data set generated during the relatively short time that humans have been flying extended missions in space. NASA has presented a legislative proposal to Congress that would allow the Agency to perform enhanced annual medical monitoring and provide diagnosis and treatment for former astronauts for medical conditions which are deemed to be associated with human spaceflight. The comprehensive preventive screening would enable NASA to minimize catastrophic issues through early detection and the additional data acquired would enable NASA to better understand the risks of spaceflight, minimize these risks, and enable future long-duration missions to Mars and beyond. The Institute of Medicine (IOM), part of the National Academies of Science, Engineering and Medicine, has issued three reports in the last two decades, emphasizing NASA's ethical and moral imperative in taking care of our astronaut corps. We would greatly appreciate Congress' support for this important proposal.

Conclusion

NASA's exploration strategy aims to pioneer multiple destinations in the solar system in an affordable and sustainable manner. In the 2020s, we will extend our capabilities deeper into cislunar space, beyond our continuous presence in LEO on ISS, to begin testing deep space exploration systems during this Proving Ground Phase of the Journey to Mars. From there, we will develop a better understanding of the risks and mitigations of sustained deep space travel, and we will continue to expand human presence in the solar system and to the surface of Mars. We will partner with industry in this endeavor and leverage private sector activity to gain key insight into technologies such as Mars entry, descent, and landing. We will also partner with the private sector in addition to SLS and Orion to support activity in cislunar space and lower the cost of space activities, and lead an international community in this activity. With constancy of purpose and support from the Congress, we look forward to extending human presence into deep space over the course of the next decade.

The Agency is well positioned to continue on its long-term mission, and, by focusing on executing the plan we have laid out, we intend to continue earning the support of future Administrations and Congresses for this plan. The progress to date has been nothing short of amazing. Findings from our partners at the Government Accountability Office (GAO) and Office of Inspector General (OIG) have highlighted areas for concern and issues that we were already working to resolve. They did not discover any problems that we were not already working. Spaceflight systems development is difficult and demanding, but we are overcoming the challenges. Around the U.S. and the world, real hardware is being fabricated and assembled, test facilities are being utilized, and people are working together to expand human presence into the solar system. These are substantive strides on the Journey to Mars. NASA is positioned for a vibrant future, and we continue to lead the world in space through a balanced program of exploration, science, technology, and aeronautics research.

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