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Statement of

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before the

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United States Senate

Mr. Chairman and Members of the Committee, I am very pleased to appear before you today to discuss our Moon to Mars (M2M) effort, including the Artemis Program. Artemis is the name of NASA's lunar exploration program that will send the first woman and the next man to the South Pole of the Moon by 2024 and develop a sustainable human presence at the Moon by 2028. Artemis takes its name from the twin sister of Apollo, the goddess of the Moon in Greek mythology.

This week, we celebrate the 50th anniversary of the Apollo-11 mission to the Moon. At this point in 1969, astronauts Neil Armstrong, Buzz Aldrin, and Michael Collins had been in flight for just over a day, with the historic lunar landing ahead of them. Now, NASA is working to build a sustainable, open architecture that returns humanity to our nearest neighbor. We are building for the long term, going to the Moon to stay, and moving beyond to Mars. We are designing an open, durable, reusable architecture that will support exploration for decades to come. Sustainability requires reusable systems and partnerships from across the commercial sector and around the world. Robotic scientific missions delivered by commercial landers will be the first Artemis elements to land on the Moon.

The Agency is incentivizing speed and drawing on commercial and international partners as it looks to land humans on the Moon within five years. NASA is completing development of both the Orion spacecraft that will carry humans to lunar orbit, and the Space Launch System (SLS) rocket that will launch Orion. NASA is pressing forward toward the Artemis 1 mission, an uncrewed test flight of Orion and SLS as an integrated system around the Moon. This will be followed by the Artemis 2 mission that will be the first test flight with human crew to the lunar vicinity aboard SLS and Orion. Then, the Artemis 3 mission will send the first crew to the lunar surface using commercial human landing services that depart from the Gateway outpost orbiting the Moon. With the rapid development of the commercial human landing services and the Gateway, we will have access to more of the Moon than ever before.

As we recognize past achievements, NASA is proud to be the standard-bearer of a global effort to advance humanity's future in space, leading the world while expanding on our Nation's great capacity for exploration and innovation. This is a role the Agency has played for over 60 years, leveraging the talent and hard work of America's skilled Government and aerospace industry workforce to push the boundaries of science, exploration, and technology development to achieve bold goals in the aviation and space arenas. Now, pursuant to Space Policy Directive-1 (SPD-1) – and consistent with the NASA Transition Authorization Act of 2017 – NASA is pursuing "an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to

bring back to Earth new knowledge and opportunities." We are working on a sustainable campaign of exploration, transitioning the International Space Station (ISS), returning humans to the surface of the Moon and lunar orbit, where we will build the systems, deep space infrastructure, and operational capabilities to expand human presence into the solar system, eventually embarking on human missions to Mars and other destinations.

NASA cannot accomplish these bold goals without the support of Congress, so I'd like to take this opportunity to thank Chairman Wicker, Ranking Member Cantwell, Aviation and Space Subcommittee Chairman Cruz, and Ranking Member Sinema for their work on crafting a new NASA authorization bill. Bipartisan support is critical for implementing our plans for the human exploration of the Moon and Mars, including the diverse elements of Artemis, such as SLS/Orion, the ground systems that support them, the Lunar Gateway and commercial lunar landers, the great science work being enabled by the Commercial Lunar Payload Services (CLPS) initiative, and advanced technologies for lunar surface operations. We appreciate the work of the Congress, which allows us to maintain a robust portfolio of aviation and space research and development activities across the Agency.

Moon to Mars (M2M)

It is important to remember that a foundational element of our Moon to Mars effort is the work being done aboard ISS. Because ISS is continuously crewed, it can be used for testing the reliability of life support systems over many years and for understanding the physiological and psychological impacts of living in space for long periods of time. The Human Research Program is responsible for understanding and mitigating the highest risks to astronaut health and performance to ensure crews remain healthy and productive during long-duration missions beyond low-Earth orbit (LEO). Existing NASA projects include a number of demonstrations that focus on key deep space habitation systems challenges including:

- Long-duration life support systems with greater reliability and fewer consumables;
- Improved environmental monitoring technologies that operate autonomously with no sample return to Earth;
- Advanced fire safety equipment that can detect, suppress, and extinguish large-scale fires;
- Next-generation spacesuit technologies that will be incorporated into spacesuits for the Moon and Mars;
- In-space additive manufacturing and other technologies with the potential to reduce logistical requirements; and
- Next-generation radiation sensors and radiation monitoring approaches.

NASA will leverage the ISS Partnership and create additional cooperative opportunities for the next steps in exploration beyond LEO. We are also leveraging the ISS Partnership to define exploration standards that will allow commercial as well as international cooperation in the exploration architecture. NASA will continue to work to enable the development of a commercial market in LEO and alternatives to a Government-directed human spaceflight infrastructure in LEO. This will help to create potentially less costly and more robust operations in LEO.

The renewed human exploration of the Moon as a stepping-stone to human missions to Mars has been part of the National Space Exploration Campaign. A sustainable lunar presence will pay dividends across diverse areas, including: American leadership; scientific discovery; technology development; expansion of the economy; and inspiration of the next generation of science, technology, engineering, and mathematics (STEM) professionals. By focusing on accelerating our near-term efforts on landing the first woman and the next man on the Moon in 2024, we will not only begin to realize these benefits sooner

than before, we'll also create momentum that will reduce the political risk of disruptive changes in direction.

NASA has long been an example of America's positive and inspirational influence in the world. As leaders in human space exploration, we've been able to help focus the efforts of the global community in achieving great things in space, such as the ongoing operation and utilization of the ISS. With America leading the way, we are building spacecraft to internationally agreed standards so more nations in partnership with NASA will have access to the Moon than ever before. Many nations are now interested in conducting scientific and commercial lunar activities, and our international partners have expressed great interest in collaboration. We're aggressively pursuing ways that other nations can contribute going forward. We must decide now whether we build on our legacy of American preeminence in science, technology, and exploration, or take a back seat and watch as other nations define our future.

Scientifically, there is intense interest in what we can discover at the Moon, and recent discoveries have rewritten our understanding of the origin and history of our Moon and solar system. For example, Lunar Reconnaissance Orbiter (LRO) mission data shows some lunar polar regions may contain abundant water ice deposits. Understanding its sources and concentrations will help us understand how the Moon formed and evolved, and might provide resources for future explorers (potentially everything from life support to rocket fuel). The farther humans venture into space, the more critical it becomes to manufacture materials and products with local resources.

NASA is developing capabilities to access low lunar orbit and the lunar surface with multiple companies providing small payload transportation services. NASA will conduct many more science investigations and technology demonstrations on the Moon, ahead of a human return, through its CLPS initiative. Lunar payloads from a variety of customers, including NASA, will fly on contracted missions starting in 2020, enabling critical technology demonstrations and scientific observations.

- In November 2018, NASA selected nine U.S. companies to bid on delivery services to the lunar surface through CLPS contracts.
- On May 31 of this year, we announced the selection of the first three commercial Moon landing service providers that will deliver science and technology payloads as part of CLPS, with the first surface delivery targeted to launch in September of next year.
- On July 1, NASA announced selection of 12 new science and technology payloads that will help us study the Moon and explore more of its surface. The selected investigations will go to the Moon on future flights through CLPS project.

These missions will acquire new science measurements and enable important technology demonstrations, whose data will inform the development of future landers and other exploration systems needed for astronauts to return to the Moon by 2024.

For 60 years, American investment in NASA has returned to America and the world advances in science, technology, medicine, education, and industry. The Apollo program helped spur the computer revolution and led to the development of countless innovations we use on Earth every day, including cooling garments for use in medicine and sports, improved dialysis machines, water purification systems, self-righting life rafts, flame resistant textiles, personal locator beacons and freeze-dried food. Investments in NASA will continue to create new technological capabilities for our Nation, and as has always been the case, many will spin off to the public with medical, safety, economic, educational, and other benefits.

Ultimately, exploration of the Moon and Mars is intertwined. The Moon is a testbed for Mars, providing an opportunity to demonstrate new technologies that are necessary for crewed Mars missions: power and propulsion systems, human surface habitats, surface mobility, *in situ* resource utilization, and other

capabilities that could help us build self-sustaining outposts in the solar system. New methods of creating, storing, and transferring propellant will help maintain our presence on the Moon and fuel the journey beyond. NASA will continue to work with industry and academic partners to mature in-space manufacturing and assembly for more sustainable exploration missions.

Generations past had the industrial revolution, the computing revolution, and the internet revolution. We believe the next economic revolution will happen in space, and the United States must lead if we are to empower future generations and secure our Nation's long-term prosperity. An emerging space economy built on resource utilization, tourism, and scientific research will power and empower countless future generations and create new jobs and industries. The investment in NASA's Moon to Mars exploration undertaking already provides direct economic benefits and creates a variety of jobs across the country. More than 3,000 companies in all 50 states are already doing work to support Artemis missions.

The Apollo program had a profound cultural impact, driving greater interest in STEM careers. NASA is committed to achieving its exploration goals, and to reigniting America's passion for space exploration, innovation, and discovery. If we bring together the capabilities and resources of our international and commercial partners to return to the Moon and continue further on to Mars, we will demonstrate to young people around the world the power of a unified purpose. It will serve as an unparalleled and inspiring example of what humankind can do when it comes together to achieve a common goal for the common good. Our efforts will involve the whole of the Nation, including the brightest minds of academia, businesses of all sizes and types, young people joining us at the beginning of their careers, and people worldwide inspired by our accomplishments and goals. The inspiration we will provide to the next generation helps us successfully draw new talent to the STEM careers of tomorrow.

Phase 1: 2024 – A New Urgency

On March 26, 2019, the Vice President announced at a meeting of the National Space Council in Huntsville, Alabama, that, at the direction of the President of the United States, it is the stated policy of the United States of America to return American astronauts to the Moon within five years and that, when American astronauts return to the lunar surface, they will take their first steps on the Moon's South Pole. On May 13, 2019, NASA submitted a revised FY 2020 budget to Congress that would provide an additional "down payment" of $1.6 billion beyond the original budget request to achieve this objective. Our approach is to leverage and build upon our existing work and plans to achieve these new goals.

Schedule performance by the SLS and Orion are critical to achieving a human return to the Moon by 2024. The Human Exploration and Operations Mission Directorate (HEOMD) completed an assessment of alternate approaches for hardware processing and facilities utilization for key components, with the goal of maintaining an early as possible Artemis 1 launch date. The NASA Office of the Chief Financial Officer performed a schedule risk assessment of the Artemis 1 launch date, including the integrated schedule and associated risk factors ahead of Artemis 1. NASA leadership is currently evaluating these results.

Artemis 1 will be followed in 2022 by Artemis 2, a crewed mission with SLS and Orion to the lunar vicinity to test critical systems and lay the foundation for a lunar surface landing by Artemis 3 in 2024. SLS, along with the Orion spacecraft and the Gateway will be our backbone for deep space exploration. NASA will use commercial services to deliver logistical supplies for the lunar missions and for transportation to the lunar surface. Having multiple transportation options has proven to be very valuable in other contexts and will be important to maintaining cost-effective, reliable access to the Moon and other locations.

One element of our exploration infrastructure is the Gateway. The Gateway will function as a way station from which NASA, its international partners, and its commercial partners, can mount robotic and human expeditions to and around the Moon. SLS and Orion can reach lunar orbit, but our crews will need a place to rendezvous before going to low lunar orbit, and ultimately to the surface of the Moon. The Gateway is that rendezvous point, located tens of thousands of miles from the surface in a Near-Rectilinear Halo Orbit. Given the urgency of a human landing in 2024, NASA and its partners will focus initially on developing and deploying the Gateway's two initial components: the Power and Propulsion Element (PPE) and a minimal habitation capability. On May 23, 2019, NASA announced the selection of Maxar Technologies, of Westminster, Colorado, to develop and demonstrate power, propulsion and communications capabilities for NASA's Lunar Gateway. Both the PPE and small habitation element will be launched on commercial launch vehicles.

NASA is conducting a series of tests inside several deep space habitation prototypes built by American companies under the Next Space Technologies for Exploration Partnerships (NextSTEP) effort to develop ideas about how astronauts will live and work on the Gateway. The Agency is evaluating the prototypes across the country this spring and summer.

For missions to the lunar surface, the current plan is for astronauts to employ a transfer vehicle to travel from the Gateway to low lunar orbit, a descent vehicle to land on the surface of the Moon, and an ascent vehicle to return to the Gateway. The vehicles will be developed by the private sector and procured by NASA. NASA is moving rapidly to support development of these critical pieces of the exploration architecture. On May 16, 2019, NASA announced the selection of 11 companies to conduct studies and produce prototypes of human landers for its Artemis lunar exploration program. These studies and prototypes will provide critical data needed to inform requirements for the Artemis 3 hardware. In the very near future, NASA will be initiating a competition under the NextSTEP effort to fund the development of these commercial lunar landing systems. To reduce the risk associated with a 2024 landing and promote a competitive environment, NASA expects to make multiple awards for these systems.

Transformative Technology for Lunar Exploration

NASA's Space Technology Mission Directorate (STMD) is investing in key transformative technologies to enable human and robotic lunar exploration with an eye forward toward Mars, fostering commercial expansion in LEO, and beyond. In FY 2020, technology drives exploration as STMD will accelerate investments in lunar surface technologies through the Lunar Surface Innovation Initiative (LSII), driving essential technologies required for humans to successfully operate on the lunar surface.

The LSII activities will be implemented through a combination of unique in-house activities, competitive programs, and public-private partnerships. LSII will also integrate systems for *in situ* resource acquisition and processing into mission consumables, including oxygen and water. This capability will reduce mission mass, cost, and risk of human exploration, leading to Earth independence.

Over the next five years, STMD will transition the key technologies below through the ground demonstration phase toward demonstrations on commercial lunar landers.

- Cryogenic Fluid Management;
- Precision Landing with High Performance Spaceflight Computing;
- In Situ Resource Utilization; and
- Surface Fission Power Capability.

In 2020, the Solar Electric Propulsion project will complete the Critical Design Review for the electric propulsion subsystem, and build qualification units to conduct qualification testing of the Solar Electric Propulsion engineering development units for the high-power electric propulsion string. The first demonstration of this system will be a 50-kilowatt-class Power and Propulsion Element for Gateway.

On June 25, 2019, the Green Propellant Infusion Mission spacecraft and the Deep Space Atomic Clock instrument were successfully delivered to orbit as part of the U.S. Air Force Space Test Program-2 mission aboard a SpaceX Falcon Heavy booster. The Green Propellant Infusion Mission demonstrates a propulsion system using a propellant that is less toxic and has approximately 40 percent higher performance by volume than hydrazine, and which will reduce spacecraft processing costs. The Deep Space Atomic Clock demonstrates navigational accuracy improvements (with 50 times more accuracy than today's best navigation clocks) for deep space missions.

Phase 2: Sustainability on the Moon – An Abiding Legacy

A sustainable exploration plan requires that we build using realistically available resources. We are designing an open, durable, reusable, and cost-effective architecture that will support exploration for decades to come. Phase 2 of our plan – achieving sustainability on the Moon – also requires partnerships from across the commercial sector and around the world, as well as reducing costs for all aspects of human spaceflight. Reducing costs will allow the Agency to invest in future deep space capabilities and use those new capabilities to conduct successful exploration missions. Sustainability also includes the ability of our infrastructure, capabilities, and facilities to effectively and efficiently support our missions, while including sufficient flexibility to meet future needs as we continue to explore. Finally, sustainability requires that we remain focused on the next goal beyond the Moon. Systems and programmatic techniques we develop for lunar exploration will be designed to contribute to human exploration missions to Mars where feasible.

As noted earlier, one component of establishing sustained American presence and infrastructure on and around the Moon is the Gateway, a spacecraft assembled in cislunar space that will be used as a staging point for missions to the lunar surface and to deep space destinations. The Gateway will not be continuously crewed like the ISS. NASA currently envisions crew visits approximately once per year on the way to the lunar surface, so a strong focus is placed on robotic activities and infrastructure to foster ongoing investigations, technology demonstrations, and operations that can be conducted autonomously between crew visits.

NASA's access to the Moon and its resources must be sustainable over the long haul. The frequency and duration of human visits to the surface will be commensurate with meeting sustainable exploration objectives that prepare for missions to Mars. Specifically, it requires the ability to cost-effectively access the Moon, conduct a variety of operations on and near the Moon, extend mission durations to weeks and months on the surface, and return safely to Earth as requirements dictate and opportunities arise. Therefore, we will evaluate future investments in the Gateway and on the lunar surface with our international and commercial partners with the goal of making lunar presence and activities sustainable.

While initial crew expeditions to the surface of the Moon will last about seven days, expanded Gateway and surface capabilities later in the decade could support surface exploration that lasts for weeks or months and test the technologies and systems needed for missions farther into the solar system, including Mars. This will be critical to supporting the Agency's plans for sustainable lunar exploration. NASA's Orion spacecraft can support roundtrip missions from Earth to the Moon for about 21 days. Traveling to the Moon in the spacecraft one way will take about six days. Once docked to the Gateway during early

lunar missions, Orion will remain active, using its supplies, thus limiting the amount of time crew can remain in deep space before returning home. With modifications, additional supplies, and possibly other systems, Orion could enable longer deep space missions for human exploration, science, technology demonstrations, and practice for missions to Mars.

NASA will also evaluate potential future investments in other assets that may improve sustainability, such as reusable landers, reusable tugs, reusable surface habitats, and rovers that will allow people to live on the Moon for extended durations, reduce the cost per person of reaching and operating on the Moon, and allow us to take advantage of the Moon as an analogue for Mars. The Moon is the proving ground for the technologies, capabilities, and programmatic techniques we will need to safely explore Mars. Per SPD-1, we are going to utilize the resources of the Moon, including the water ice that is available to use for life support, water to drink, air to breathe, and also rocket fuel. Ultimately, the Moon will serve as a stepping-stone, a training ground, and a platform to strengthen commercial and international partnerships and prepare for future human missions to Mars and other destinations.

On to Mars

Mars remains the horizon goal for NASA's human exploration program, but it is important to note that we are at Mars now, with a growing number of robotic assets that will pave the way for future human explorers. The Agency has been exploring Mars for over 50 years, and we have had a robotic presence there since 1997. Our robotic missions in orbit and on the surface of Mars have revealed valuable data about the locations and abundance of resources on the planet. Right now, the Mars Reconnaissance Orbiter, Mars Odyssey, MAVEN, Curiosity Rover, and InSight are operating at the Red Planet, and they will soon be joined by the Mars 2020 rover and Mars helicopter. The Agency will continue the search for life with the Mars rover in 2020, and begin planning a first-ever sample-return Mars mission. All of these efforts will provide significant support for human Mars missions.

Much of the work planned under Artemis is applicable to future human exploration of the Red Planet. Artemis will enable us to utilize the Moon to prove the technologies, capabilities, and new business approaches for future missions to Mars:

- The ISS, future commercial space stations, and Gateway will help demonstrate autonomous spacecraft systems management and long-term reliability of systems needed for Mars-duration missions.
- Technologies such as advanced Solar Electric Propulsion and flight systems to be developed and demonstrated under the Artemis Program will help bring human Mars missions within reach.
- Similar to our plans for Artemis, we will likely stage human landers from a reusable, orbiting platform for missions to the surface of the Red Planet; using Gateway in this way for Moon landing enables us to demonstrate a precision landing capability, a human-class ascent vehicle, and operational node/safe haven concepts applicable to Mars.
- The Moon is a proving ground for Mars. We are incrementally preparing for astronaut missions from hours away from Earth, to days, to years. Crew aboard the ISS are about 250 miles off the Earth, whereas the Moon is a quarter million miles away, and Mars is 34 million miles from home. At the Moon, crew will learn to live away from the ability to return to Earth for weeks at a time and, ultimately, months at a time before we send them on years-long trips to Mars.
- The farther humans venture into space, the more critical it becomes to manufacture materials and products with *in situ* resources rather than using multiple launches to provide the supplies needed for long-duration missions; the Moon provides opportunities to test technologies to access, extract and use those resources (e.g., water ice).

- We are developing dust-mitigation strategies that can be evaluated on the Moon before going to Mars.
- Sustained presence on the lunar surface provides opportunities to demonstrate capabilities for long-duration surface habitation, including advanced surface suits, human-scale pressurized surface mobility, and progressively Earth-independent medical and behavioral health operations to support crew.
- Surface operations at the Moon allow us to demonstrate systems and procedures for high-capacity surface power generation and storage, operating with communications delay, and conducting *in situ* science analysis.
- NASA could use commercial partnership approaches pioneered in LEO and advanced at the Moon for cargo delivery and other purposes related to Mars exploration.
- NASA will carefully trade the benefits of testing on the lunar surface against Earth testing and simulation.

We have asked Congress for additional resources to get to the Moon by 2024, which will enable us to get to Mars more quickly and safely. The work we accomplish at the Moon over the next decade and beyond will ensure we can send the first humans to Mars.

Conclusion

Exploring the Moon will help create a vibrant future that will continue U.S. leadership in space and establish a strategic presence on the Moon; lead to groundbreaking scientific research and technology development; expand America's global economic impact; grow U.S. industry and international partnerships; and prove technologies, capabilities, and new business approaches for future human missions to Mars. Beyond this, our Moon to Mars effort will inspire the Artemis generation, a new generation of students to pursue STEM careers, just as Apollo did for an earlier generation.

There are two types of risks inherent in carrying out ambitious human spaceflight programs: political and technical. With our workforce and partners, we will retire the technical risk, but political risk remains a factor. NASA has the support of this Administration to take our next giant leap, but we need additional resources and support from Congress to make an accelerated human return to the Moon by 2024 a reality. We appreciate the Committee's consideration and support, and I would be pleased to respond to your questions.