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Chairman Cruz, Ranking Member Sinema, Members of the Subcommittee, thank you for the invitation to appear before you with such an extraordinary and distinguished panel to discuss my thoughts on the topic of today's hearing: "NASA's Exploration Plans – Where We've Been and Where We're Going."

Then: The Apollo Program and an Epochal Mission

More than 50 years ago, the Apollo program began, ultimately resulting in one of humankind's most extraordinary achievements. Undertaken as part of the Kennedy administration response to the Soviet Union, and in the context of a perceived "missile gap" between U.S. and Soviet capabilities, the effort was virtually on a war footing and had a specific mission focus – "landing a man on the moon and returning him safely to the Earth" within a decade. This mission objective had a much broader and even more urgent underlying goal, however – to demonstrate the superiority of the technical, economic, and political system represented by American ideals of freedom and democracy versus that of a closed, communist state.

The mission outlined by Kennedy may not have survived had he not been assassinated – and if it had survived it may have evolved to a different mission, perhaps with a Russian partner. We will never know. In President Johnson's hands, however, Kennedy's space legacy – both the goal and the mission – became codified in a way that has never happened since in human space exploration.

Mission readiness was the driving force for the entire Apollo program. To achieve the mission certain capabilities had to be developed. These included standing up a human spaceflight organization capable of developing and delivering a super heavy lift vehicle, a crew capsule, ground systems, EVA suits, crew systems, and related equipment. An entire operations concept and organization called "Mission Control" had to be invented, in turn supporting and supported by development and execution of procedures, schedules, simulations, training, a logistics system (including communications and tracking both on the ground and from ground to space and back), medical support, and much more. Each capability was developed as part of a learning sequence with many moving parts, each building toward the successful landing and safe return of the crew of Apollo 11. The goal was a geopolitical one, the Apollo program was the means to achieve it, and the extraordinary work, time, and treasure it took to meet it - involving over 400,000 Americans and at the cost of $300B in adjusted dollars for the entire program[1] - was realized

[1] http://www.planetary.org/press-room/releases/2019/apollo-cost-analysis.html

between July 16 and 24, 1969, with human beings setting foot on another celestial body 50 years ago on July 20.

Now: A Focus On Capability

With regard to today's goals, it should be said from the beginning that the primary objective viewed with a national lens remains geopolitical, although it is a different geopolitical objective. No longer in a race to the Moon, United States leadership in space depends upon establishing a foundation that provides other nations and a nascent space-based economy with security and assurance regarding our national intentions and long-term commitment to aspire, inspire and achieve – in short, *to lead.* Space remains a strategic, competitive domain among nations. For example, China is pushing forward with technology, science, investment, a new space station in low Earth orbit, and lunar aspirations, and has announced development of a super heavy lift vehicle (SHLV) for human space exploration. Russia remains an active partner with us on the International Space Station but also has announced plans for an SHLV. For the U.S. to push forward and support our endeavors and those of our friends, we must be "out there" – physically present, with national assets at the ready, and we must be there sooner rather than later.

The success of the Apollo program – at great cost in treasure and in human lives – created a near-mythical template in the minds of both NASA and the public that has been at the heart of controversy about the role of the space program ever since, resulting in oft-repeated commentary as to whether NASA has a "mission". The answer is emphatically "yes", but not in the same way as Apollo. Instead, we are embarked upon a plan to create, manage, and execute deep space activities based on the development of national capability, defined here as the ability to achieve a variety of desired outcomes in a specific operating environment. Much like the development of military capability, a sustained national capability requires technical systems and equipment needed to perform the operations for which they are designed that also support a variety of missions that may not be known when the capability is being developed. These are typically long lead-time national assets that exist to perform certain functions necessary to meet operational requirements. As such they are sustained by national investment as a guarantee against economic downturns and policy shifts that may accompany short-term Administration and/or Congressional priorities.

Accordingly, the United States is developing core capabilities to enable our return to deep space: A super heavy launch vehicle (SHLV), a modern crew vehicle capable of long-duration missions when paired with habitats and consumables, and ground-based infrastructure needed to support those missions. Dubbed the Space Launch System (SLS), the Orion crew vehicle, and Exploration Ground Systems respectively, these strategic assets are the foundation upon which national goals in human deep space exploration will rest for the foreseeable future. In addition, the Artemis Program will engage industry and international partners, seeking to align national objectives with those of commercial enterprises and global collaboration in the exploration of deep space wherever practicable.[2]

The momentum established by the current administration with its focus on the Moon is a welcome one, but as report after report has shown NASA is asked to do too much with too little

[2] https://www.nasa.gov/sites/default/files/atoms/files/ger_2018_small_mobile.pdf

and this is no exception. Acceleration must be balanced with program risk and mission assurance, and forward momentum must be matched by significant national investment above present levels.

Happily, this increased investment will find a much broader portfolio in science, technology, and exploration than when the Apollo program began 60 years ago. A revitalized space industry is building on previous government investments and experience gained during that extraordinary effort. New manufacturing methods, technologies, and advanced computing capabilities are reducing costs, encouraging new entrants, building new capacity, and attracting billions of dollars in investment in the emerging space sector. Meanwhile, NASA has led the development of a global spaceflight community, collaborating with international partners while helping to open the door to human spaceflight and space science for over 100 countries via participation on the International Space Station.

Today's need for operational readiness is every bit as great as during the Apollo program, but the overarching goal is less specific, more open-ended. While the recently-announced Artemis program, with its goal of returning Americans to the lunar surface by 2024 is a worthy effort, the "Artemis Lunar Landing-1" mission does not represent fulfillment of a policy objective in the same sense as did Apollo 11. Today, the policy objective is to establish a sustainable, strategic human presence beyond low Earth orbit, first at the Moon and then beyond, with an eye toward Mars. The key words here are "sustainable" and "strategic". To succeed in this endeavor, however, several things must change.

Timely and Sufficient Funding

In the decades since the current, regular order for authorizing and appropriating tax dollars has been established (1974), Congress has managed to pass all of its required appropriations measures on time on less than half a dozen occasions.[3] It is true that Congressional support for NASA and for human space exploration has been consistent. That said, for NASA programs, as for all long-lead time programs spanning years, last-minute political maneuvering, government shutdowns, delayed receipt of funds, and general instability and unpredictability of funding invariably creates inefficiency in program management and execution, forcing compromises in program planning that add cost, schedule and risk.[4] In addition, report after report has found that NASA's tasking and budget are mismatched.[5] Alternate acquisition and procurement approaches when technologies are well understood is a useful means to reduce costs, but relying on industry to drive down costs while at the same time increasing speed of delivery, or seizing upon alternate means for acquisition without consideration of risk management implications, amounts to wishful thinking. Such approaches do nothing to change that fact that at no time since Apollo, with all of its extraordinary resources, has any human-rated system been deployed less than 4 years later than originally intended, no matter who is building it.

[3] https://www.pewresearch.org/fact-tank/2018/01/16/congress-has-long-struggled-to-pass-spending-bills-on-time/
[4] https://www.hsdl.org/?view&did=794133
[5] See, for example: https://sites.nationalacademies.org/cs/groups/depssite/documents/webpage/deps_080254.pdf

The Administration has proposed $1.6B to begin the process of accelerating our human space exploration program. In addition, the NASA Administrator has estimated it will take between $20 and $30B over currently anticipated funding levels to meet more aggressive timelines. While funding increases are always a political challenge, it is worth noting that the benefits of 10X that amount in adjusted dollars invested in the Apollo program are evident to all, and form the foundation both for today's national effort and for the growing entrepreneurial sector.

It is absolutely true that that inefficiencies in development and execution within government programs should be addressed. Congress can help by regularizing its own process. The hearing to which these remarks is addressed is a welcome aspect of that process.

Acquisition and Procurement Reform

As has been recognized by Congress over the past many years, the nature of the policy and regulatory framework guiding exploration and development of space is crucial, providing government, industry and the investment community alike with stable, predictable operating environments. The importance of stability also has been recognized across various Administrations and very recently has been reflected in the agreement upon 21 "Guidelines on the Long-Term Sustainability of Outer Space Activities" within the UN's Committee on the Peaceful Uses of Outer Space (UN COPUOS).[6]

Hand-in-hand with stability in "light touch" regulation however is the need for streamlined acquisition processes. As I testified before the National Space Council in February of 2018, the fiscal, programmatic, reporting and management burdens associated with government contracting and oversight cannot be overstated. The slow nature of acquisition and the costs and schedule associated with program startup also pose a threat to technology development and insertion into some of our most strategic programs, threatening U.S. leadership and security. This is not to say that traditional contracting should be abandoned. On the contrary, cost-plus contracts for managing large development programs with significant R&D components provide stability, reduce business risk and support the aerospace and defense industrial base that is so critical to U.S. security. That said, the ability to ramp up programs with much greater speed than typically seen together with renewed focus on accountability and constraints on cost and schedule growth are of primary interest in reform.[7]

The use of Other Transactional Authority (OTAs) and Public Private Partnerships (P3) may provide more flexibility than traditional contracting and, in some cases, offer economic incentives, but at the cost of reduced transparency. Each of these approaches may take many forms but their success depends upon informed allocation of risk on each side of the government-business relationship, a realistic business case in the case of P3 (an indispensable requirement) and the means to align business objectives with the public (national) interest. The rapidly-accelerating range of procurement activities in both the DoD and NASA requires the ability to evaluate acquisition models, understand their strengths and weaknesses for differing applications, situations and goals, assess business cases, grasp the complexities of risk allocation and management associated with different models, and understand the range of economic

[6] http://www.unoosa.org/oosa/en/ourwork/topics/long-term-sustainability-of-outer-space-activities.html
[7] http://exploredeepspace.com/multimedia/coalition-statements/2018-02-22/

incentives and their likely downstream effects. Adopting an acquisition posture that balances risk, cost and schedule with the goal of rapid development and deployment of capabilities may require retraining the procurement workforce across the government.

<u>Education and Diversity in the Workforce</u>

Preparation and development of the A&D workforce is not limited to procurement professionals. It must begin much earlier and span a multitude of disciplines. The United States has remained in the upper third of countries for 4-12 grades students in math and science for the past 15 years though our test scores remain relatively flat.[8] Of those students who eventually seek employment in the Aerospace and Defense (A&D) workforce, 71% of young A&D professionals report they first became interested in these careers during their grade school years. Continuing emphasis upon superior preparation and broad educational opportunities is critical to U.S. leadership across STEM disciplines, including in space.

In addition, and despite significant effort, the diversity of the A&D industry looks much the same as it did four decades ago. Greater diversity in a workforce has been demonstrated time and time again to result in higher rates of innovation, invention, and unique problem-solving and is key to both global competition and cooperation. At the same time, the shift in economic demographics nationwide since 2008 has resulted in a higher proportion of Americans remaining at work. This is also true of A&D; 29.8% of workers are 55 years of age or older.[9] On the one hand, this benefits the industry since it requires legacy skills and experience in aerospace, electrical, mechanical and electrical engineers. On the other, the industry also requires skills in cognitive computing, artificial intelligence and materials. At present, terrestrial high technology careers in these fields are attracting the best and brightest young professionals. NASA and the Department of Defense must not only compete with them but with quicker-moving entrepreneurial firms.[10]

While job competition is good to spur interest in STEM careers and to drive up salaries, from the point of view of national interest, the stresses on the workforce (and the hundreds of small businesses that provide the A&D backbone in this country) are increasing, creating "talent gaps" in some critical fields ranging from IT to manufacturing talent – all of which are needed in space. Reorienting and revitalizing human capital processes, increasing investment in trade schools, and even embedding space into higher education curriculums in non-traditional fields are among the means to help address the growing workforce development issue.

The Near Future: Artemis and the Moon

Addressing funding, acquisition, and workforce development and diversity are fundamental to get to where we are going – which is to the Moon and then to Mars. As pointed out by the Committee on Human Space Exploration of the National Academies, upon which I served, there are many roads the United States and its industry and international partners may take to create a

[8] https://www.brookings.edu/blog/brown-center-chalkboard/2017/04/07/what-international-test-scores-reveal-about-american-education/
[9] https://www.aia-aerospace.org/wp-content/uploads/2018/05/AviationWeek-WhitePaper-REVISED-101717.pdf
[10] https://spacenews.com/op-ed-talent-gap-jeopardizes-space-business-national-security/

sustainable presence beyond low Earth orbit. The "Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration" report (herein after referred to as "The Pathways Report"),[11] published in 2014 after two years of study and debate, described several sequences and risk postures for NASA's human exploration program but leaned heavily toward the Moon as an initial destination. The Pathways report also advised Congress and NASA to focus on "feed forward" development – that is, to maximize the potential for a sustainable approach by designing in readiness and flexibility. Among other means to achieve this design philosophy is to develop capabilities that can be deployed over decades.

Space Policy Directive-1, signed by President Trump in late 2017, is in alignment with the NASA Authorization Acts of 2008, 2010, and 2017 in its call for NASA to "lead 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."[12] While the Administration's target date of 2024 for the Artemis Lunar Landing-1 mission has injected some much-needed urgency into NASA's planning and programs, one danger of shifting our focus from developing a longer-term capability to focus on a near term date is that we may inadvertently sacrifice flexibility and capability for the sake of meeting a short-term mission objective.

In military science, a major area of endeavor is to find methods to achieve missions that may not have been understood when systems were under development, using those capabilities that have since come on line both as intended and by exercising new concepts. With regard to deep space exploration, NASA plans to achieve flexibility at the moon by constructing a lunar orbiting station known as Gateway in partnership with industry and with international partners. Gateway is not, as some have stated, a waste of money or an unnecessary way station. Instead, Gateway is a component of a larger architecture that increases feed forward opportunities. The Gateway greatly simplifies our ability to aggregate hardware in the vicinity of the Moon – that is, to provide a central hub for docking, brief habitation, emplacement of consumables, descent and ascent vehicles for transportation to the lunar surface, transfer vehicles, etc. It is true that these can be aggregated in orbit without a Gateway; however, the transportation model becomes more complex and the timing less forgiving.

For example, without a Gateway, lunar sorties with humans are limited to four days due to the 21-day mission profile for the Orion crew vehicle. With the Gateway, crew are not solely dependent upon Orion's systems but can rely on habitation and access to consumables that are present at the Gateway, enabling longer missions on the surface. In addition, over time the Gateway will enable in-space reusability by serving as a docking and refueling hub, greatly simplifying transportation requirements over time.

Longer surface missions in turn will enable a variety of activities to be undertaken by a variety of participants. Entrepreneurial firms are teaming with investors and also with established companies to develop technologies aimed at building up infrastructure on the Moon, making use of lunar regolith as raw material as one example. With regard to science, there is still a great deal

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[11] https://www.nap.edu/catalog/18801/pathways-to-exploration-rationales-and-approaches-for-a-us-program
[12] https://www.whitehouse.gov/presidential-actions/presidential-memorandum-reinvigorating-americas-human-space-exploration-program/

to learn. The Moon has been called "The Rosetta Stone"[13] of the solar system, with evidence locked within that has already taught us a great deal about the formation of the Earth-Moon system but also has implications for outer bodies. We have explored only 5% of the surface; there is a great deal more to learn.

Finally, Gateway is the next logical step in developing a command and logistics capability that is extensible not just to the Moon but beyond the Moon toward Mars. The Gateway itself is a prototype, and evolution of lessons learned over the past 50 years and in particular from the International Space Station to create habitable space and systems to support human life and work in deep space. As the Gateway evolves, it provides an opportunity for broader international and industry participation and utilization, providing options for continuing deep space development that do not necessarily depend upon descending to the surface.

Our Horizon Goal: Mars (and Beyond?)

The Moon is an important stepping stone with geopolitical, scientific and the potential for commercial benefits. It is entirely possible that some of us will remain there for decades – for example, experimenting with in situ resource utilization (ISRU) technologies, conducting science, or seeking to extend our terrestrial economy to incorporate utilization and capitalization of resources found on or below the lunar surface. What we learn there will not only create opportunities in cislunar space but open new discoveries and knowledge that will help us as we look toward Mars. The Moon is not an end goal, but a beginning - a next step enabling the migration of technology, heavy industry, and humanity itself off the Earth and into the solar system at a scale that is no longer constrained by a single planet, our original home.

The Pathways report concluded that Mars is the "horizon goal" for the human exploration of space, the destination upon which the aspirations of all international space programs converge, and the farthest viable destination for human beings given foreseeable advances in technology. It is essential that this be an international effort, led by the United States in collaboration with others. The International Space Station has taught us that a multilateral enterprise such as Mars will bring forth intellectual capital, scientific abilities, research, engineering and interest in peaceful technology on the part of many nations. An international human Mars program, led by the United States, will build and expand on the foundation created by the ISS as well as lessons learned at the Moon.

At the same time, pushing further into deep space than humans have ever gone before offers the potential for technology breakthroughs – just as it did 50 years ago – unleashing American industry and investment in new and powerful ways. The fundamental barriers and challenges to planning and executing all large-scale enterprises – exploring space, mitigating climate change, controlling disease, or managing the rising global demand for clean water – are similar, whether on Earth or in space. Two of the most important needs in space - the availability and processing of water for life support and eventually propellant, and energy needs – obtaining, storing, managing, and transmitting energy or power - have direct relevance to many problems facing today's world. With thought and proper planning, technology opportunities and challenges on

[13] https://www.theatlantic.com/magazine/archive/1963/08/why-land-on-the-moon/361529/

the Moon and particularly at Mars with the constraints imposed by its vast distance from Earth can find natural alignment with many of humanity's most pressing terrestrial problems.

In Closing…

Perhaps most importantly, our nation needs the next generation of young scientists and engineers to advance our quality of life and remain globally competitive. The citizens of the United States also need a far better understanding of science and technology in order to exercise fully the rights and responsibilities of citizenship. The very future of our democracy depends on it. Nothing stimulates interest like truly great goals that require us to develop ourselves and advance the human condition as well as our technology in order to achieve them. Continuing the work begun with Apollo, returning to the Moon, and then reaching for the horizon of Mars, is just such a goal.