KEEPING OUR SIGHTS ON MARS: A REVIEW OF NASA'S DEEP SPACE EXPLORATION PROGRAMS AND LUNAR PROPOSAL

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE AND AERONAUTICS

OF THE

COMMITTEE ON SCIENCE, SPACE, TECHNOLOGY

HOUSE OF REPRESENTATIVES

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May 8, 2019

Appendix II: Additional Material for the Record

KEEPING OUR SIGHTS ON MARS: A REVIEW OF NASA'S DEEP SPACE EXPLORATION PROGRAMS AND LUNAR PROPOSAL

WEDNESDAY, MAY 8, 2019

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON SPACE AND AERONAUTICS,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to notice, at 2:18 p.m., in room 2318 of the Rayburn House Office Building, Hon. Kendra Horn [Chairwoman of the Subcommittee] presiding.

SUBCOMMITTEE ON SPACE AND AERONAUTICS
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

HEARING CHARTER

Keeping Our Sights on Mars: A Review of NASA's Deep Space Exploration Programs and Lunar Proposal

Wednesday, May 8, 2019
2:00 p.m.
2318 Rayburn House Office Building

PURPOSE

The purpose of the hearing is to review the National Aeronautics and Space Administration's (NASA's) deep space human exploration programs, including proposed lunar activities and the budgetary resource requirements for those activities, in the context of the long-term goal of sending humans to the surface of Mars.

WITNESSES

- **Mr. William H. Gerstenmaier,** Associate Administrator, Human Exploration and Operations, National Aeronautics and Space Administration
- **Mr. Mark Sirangelo,** Special Assistant to the Administrator, National Aeronautics and Space Administration
- **Dr. Jonathan Lunine,** Director, Cornell Center for Astrophysics and Planetary Science, Co-Chair of the Former Committee on Human Spaceflight, National Academies of Sciences, Engineering, and Medicine
- **Dr. Patricia Sanders,** Chair, Aerospace Safety Advisory Panel
- **Mr. J. Walter Faulconer,** President, Faulconer Consulting Group

OVERARCHING QUESTIONS

- *What are the goals, objectives, plans, and budgetary requirements for the Administration's proposal to send humans to the lunar surface in 2024 and to sustain a long-term presence there?*
- *To what extent do the Administration's proposed lunar plans contribute directly to buying-down the technical and overall risks involved in a human mission to Mars?*
- *What are the safety, technical, and programmatic risks associated with the lunar proposal?*

BACKGROUND

The NASA deep space human exploration program and activities include the heavy-lift Space Launch System (SLS), the Orion crew vehicle, Exploration Ground Systems (EGS), and Exploration Research and Development. The International Space Station (ISS), which organizationally exists in the low Earth orbit (LEO) and Spaceflight Operations program account, supports future deep space exploration activities through human health research, technology demonstrations, human spaceflight operations, and knowledge gained from astronauts' living and working in space.

In March 2017, the NASA Transition Authorization Act of 2017 was enacted into law.[1] The Act reiterates previous NASA Authorizations regarding a stepping-stone approach to human exploration and adds language on achieving the objective to human exploration of Mars, as funding allows.

In December 2017, President Trump issued Space Policy Directive-1, which amended existing National Space Policy Directive-4 of June 2010 to include the "*return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations.*"[2] Subsequently, NASA organized its human exploration programs to focus on the Moon.

Exploration Campaign as Proposed in the Fiscal Year (FY) 2020 NASA Budget Request

The NASA exploration budget request for FY 2020 is combined under the Exploration Campaign Total budget line, as detailed in the table below[3] and proposes a total of $10.7 billion for FY 2020, a 2 percent cut from the FY 2019 appropriation. The FY 2020 budget request prioritizes human exploration and lunar activities with increased funding for these objectives. Under the FY 2020 proposal, NASA would target a 2028 human landing on the Moon. However, two weeks after the release of the FY 2020 budget request for NASA, the White House directed NASA to work toward a 2024 lunar landing. NASA Administrator, James Bridenstine, testified before the Committee on April 2, 2019[4] and committed to providing further details on the accelerated lunar landing proposal and a budget amendment to the Committee by about April 15, 2019. The Committee has not yet received a revised lunar plan, a budget amendment that includes annual resource requirements, or a proposed acquisition approach. Administrator Bridenstine also testified before the Senate Committee on Appropriations, Subcommittee on Commerce, Justice, Science, and Related Agencies on May 1, 2019 where he did not provide details on a lunar plan or budget amendment.

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[1] P.L 115-10.

[2] Presidential Memorandum on Reinvigorating America's Human Space Exploration Program, December 11, 2017. https://www.whitehouse.gov/presidential-actions/presidential-memorandum-reinvigorating-americas-human-space-exploration-program/

[3] Table from page EXC-1, NASA FY2020 Budget Request Congressional Justification

[4] "A Review of the NASA FY2020 Budget Request," April 2, 2019. https://science.house.gov/hearings/a-review-of-the-nasa-fy2020-budget-request

Budget Authority (in $ millions)	Actual FY 2018	IOP FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Exploration Campaign TOTAL	**$10,449.0**	**$10,927.6**	**$10,712.3**	**$11,147.1**	**$11,542.3**	**$12,637.9**	**$13,068.0**
Deep Space Exploration Systems	$4,790.0	$5,050.8	**$5,021.7**	$5,295.5	$5,481.4	$6,639.0	$7,042.3
Exploration Technology	$760.0	$926.9	**$1,014.3**	$976.1	$995.4	$964.4	$943.1
LEO & Spaceflight Operations	$4,749.2	$4,639.1	**$4,285.7**	$4,369.5	$4,369.5	$4,235.5	$4,182.3
Exploration Campaign COF	$119.8	$42.8	**$71.6**	$0.0	$0.0	$0.0	$0.0
Elements of Science+	$30.0	$268.0	**$319.0**	$506.0	$696.0	$799.0	$900.3
Change from FY 2019 PBR			**$-215.3**				
Percentage change from FY 2019			**-2.0%**				

+Elements of Science: Lunar Discovery & Exploration Program and Mars Sample Return

National Academies' Pathways to Exploration Report

In June 2014, the National Academies released *Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration*, referred to hereafter as *Pathways*.[5] The study was carried out pursuant to the NASA Authorization Act of 2010.[6] The report entailed an "*explicit examination of rationales, along with the identification of enduring questions,* [which] *set the task apart from numerous similar studies performed over the preceding several decades, as did the requirement that the committee bring broad public and stakeholder input into its considerations.*"

The National Academies' Committee on Human Spaceflight, which authored the *Pathways* report, concluded that a "*sustainable program of human deep-space exploration requires an ultimate "horizon" goal that provides a long-term focus that is less likely to be disrupted by major technological failures and accidents along the way or by the vagaries of the political process and the economic scene.*" The committee found that "*the horizon goal for human space exploration is Mars,*" having observed that "*all long-range space programs, by all potential partners, for human space exploration converge on*" that goal.

With Mars as the ultimate horizon goal, the study committee concluded that "*NASA can sustain a human exploration program that pursues the horizon goal of a surface landing on Mars with meaningful milestones and simultaneously reasserts U.S. leadership in space while allowing ample opportunity for substantial international collaboration—but only if the program has elements that are built in a logical sequence, and when it can fund a frequency of flights sufficiently high to ensure the maintenance of proficiency among ground personnel, mission controllers, and flight crews.*"

The committee further concluded that the best way to achieve a sustainable human exploration program that is responsive to their findings on rationales and enduring questions is to "*develop a program through the rigorous applications of a set of pathway principles.*" The committee

[5] National Research Council. 2014. *Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration.* Washington, DC: The National Academies Press. https://www.nap.edu/catalog/18801/pathways-to-exploration-rationales-and-approaches-for-a-us-program

[6] Section 201, P.L 111-267.

defined a "pathway" as "*a specific sequence of intermediate accomplishments and destinations normally of increasing difficulty and complexity, leading to an ultimate (horizon) goal, with technology feed-forward from one mission to subsequent missions*". The highest-recommended pathway principles included: committing to an exploration pathway beyond LEO; engaging international partners early in the design and development of the pathway; defining steps that foster sustainability and maintain progress on the horizon goal; creating a risk-mitigation plan, including decision rules for off-ramps as necessary; and establishing pathway characteristics that maximize the overall scientific, cultural, economic, political, and inspirational benefits without sacrificing progress toward the long-term goal.

The study committee examined three pathways, each with a Mars horizon goal, in terms of the trade-offs among schedule, development risk, affordability, and ISS lifetime (considering decommissioning dates of either 2020 or 2028):

- **Asteroid Redirect Mission (ARM)-to-Mars pathway** would start with astronaut interactions with a near-Earth asteroid in its native orbit, then on to the Martian moons, and finally to the Martian surface.[7]
- **Moon-to-Mars pathway** would use the Moon as a testing and development platform to mature Mars-relevant technology and do scientific exploration of the lunar surface.
- **Enhanced Exploration pathway** would begin with activities in cislunar space, then proceed to an asteroid, to lunar surface missions and an outpost, then to the moons of Mars, and then to the surface of Mars.

In considering budgets, the committee concluded that "*A continuation of flat budgets for human spaceflight is insufficient for NASA to execute any pathway to Mars and limits human spaceflight to LEO until after the end of the ISS*," and further that, even with annual increases to the NASA human spaceflight budget to keep pace with inflation, "*technical and operational risks do not permit a viable pathway to Mars.*" The committee determined that increasing the NASA budget such that the funding for human spaceflight could increase annually by 5% (twice inflation) "*would enable pathways with potentially viable mission rates, greatly reducing technical, cost, and schedule risk.*"

The report identified the following technological capabilities as high priorities for a human mission to Mars, and specifically called out the first three as the top priorities:

- **Mars Entry, Descent, and Landing (EDL)**
- **Radiation Safety**
- **In-Space Propulsion and Power**
- Heavy Lift Launch Vehicles
- Planetary Ascent Propulsion
- Environmental Control and Life Support Systems (ECLSS)
- Habitats
- Extravehicular Activity (EVA) Suits
- Crew Health

[7] NASA had been following a program along the ARM pathway, but the program was closed out in June 2017.

- In-Situ Resource Utilization (ISRU) from the Martian Atmosphere

The report includes an assessment of the technical, regulatory, and cost/schedule challenges and capability gaps associated with each of these high-priority technologies.

Evaluation of a Human Mission to Mars by 2033

Pursuant to the NASA Transition Authorization Act of 2017,[8] NASA requested that the Institute for Defense Analyses Science and Technology Policy Institute (STPI) conduct a study on the technical and budgetary feasibility of launching a human spaceflight mission to Mars by 2033. The report, "Evaluation of a Human Mission to Mars by 2033,"[9] hereafter "the Mars 2033 report," was transmitted to Congress in March 2019.[10] The report was based on NASA's *National Space Exploration Campaign Report,*[11] discussions with NASA personnel, and publicly-available documents, including the FY 2019 budget request and presentations to the NASA Advisory Council (including the notional plan to return humans to the Moon in 2028, although the new direction from Vice President Pence in March 2019 moves that goal to 2024).

The main architectural elements of a human orbital mission to Mars are the heavy-lift SLS, the Orion crew vehicle, the Gateway, and the notional Deep Space Transport (DST) vehicle. The Mars 2033 report assigned the following risk levels for these components to a human spaceflight mission orbiting Mars:

- **SLS/Orion: Low –** *"due to long development programs and ongoing testing."*[12]
- **Gateway: Medium** – as some technologies have not yet been adequately demonstrated. The first module will be the Power and Propulsion Element, currently planned for launch in 2022. However, because of schedule constraints, ground testing for its major thruster system is not planned, which contributes to the medium technological risk. Other risks include the autonomous environmental monitoring for its uninhabited period of time as well as deep space, human-rated batteries.
- **DST: High –** because *"the DST requires several medium and high-risk technologies,"* most notably the ECLSS. Other areas of medium to high risk include cryogenic propellants, system integration, space suits, and propulsion. Several technologies are at low technological readiness levels and would require several years of development time to be ready for full implementation. Some elements would not be significantly matured

[8] Section 435, P.L 115-10.
[9] IDA Science and Technology Policy Institute. 2019. "Evaluation of a Human Mission to Mars by 2033." https://www.ida.org/idamedia/Corporate/Files/Publications/STPIPubs/2019/D-10510.pdf
[10] STPI submitted a prior version of the report to NASA in December 2017. After Space Policy Directive-1 was released in December 2017, STPI was asked to update the report, and to use the NASA Exploration Campaign Report that was transmitted to Congress in September 2018 as the basis for NASA's exploration plans.
[11] NASA. 2018. *National Space Exploration Campaign Report*. Submitted pursuant to Section 432(b) of the NASA Transition Authorization Act of 2017 (P.L. 115-10).
https://www.nasa.gov/sites/default/files/atoms/files/nationalspaceexplorationcampaign.pdf
[12] However, since the completion of the report, an April 26, 2019 article in *Ars Technica* noted that NASA announced that it anticipates further delays in SLS launch dates and requested in its FY 2020 budget request to defer development of upgraded SLS variants which would enable heavier lift capability.

by the Gateway or lunar surface activities and thus would require additional research and development before use at Mars.

The Mars 2033 report also assessed the risks to human health in the orbital mission to Mars and found that *"a review of internal NASA planning documents and academic literature reveals that the understanding of human health risks associated with a 1,100-day human orbital mission to Mars is limited."* STPI additionally found that NASA's current approach to addressing human health risk factors for a mission to Mars presented a high risk because the plan lacked *"sufficient detail in both evidence and strategy to justify the predicted timeline to develop risk mitigation strategies, or even estimate a realistic cost to retire the risks."*

Given the notional plan to land humans on the Moon in 2028 presented to the advisory committees in November and December,[13] STPI assessed the feasibility of potential timelines for launch of a human spaceflight mission to orbit Mars:

- 2033: *"infeasible under all budget scenarios and technology development and testing schedules"*
- 2035: *"may be possible under budgets that match 1.9 percent real growth, but carries high risks of schedule delays due to complex technology development, testing, and fabrication schedules for the DST; may require reducing the scope of lunar missions; and reduces NASA's ability to mitigate risks to human health"*
- 2037: *"the earliest the DST could feasibly depart for Mars assuming a small budget increase or smoothing budgets over two time periods in the 2030s"*
- 2039: *"a more realistic timeframe if there are delays or budget shortfalls affecting the acquisition or testing of the DST"*

In comparison, the *Pathways* report states *"The Moon-to-Mars pathway could yield a landing between 2043 and 2050."*

Aerospace Safety Advisory Panel 2018 Annual Report

The Aerospace Safety Advisory Panel (ASAP) was chartered by Congress in 1968 to advise and make recommendations to the NASA Administrator and Congress on safety aspects of NASA activities. The ASAP prepares an annual report to convey issues and concerns it has identified at its meetings held during the year. While there are several areas related to Exploration discussed in the 2018 ASAP Annual Report,[14] selected statements from the report are highlighted below:

- *"In order to mitigate the considerable risk of human exploration in the far reaches of space, it is imperative that NASA maintains a persistent presence in LEO where it can test the technologies necessary for interplanetary voyages with its requisite life support and to continue its understanding of the impacts of space travel on human physiology."*

[13] e.g., Presentation by William H. Gerstenmaier to the NASA Advisory Council, "NASA Exploration Update," December 10, 2018.
https://www.nasa.gov/sites/default/files/atoms/files/nasa_exploration_update_dec2018_tagged.pdf
[14] Aerospace Safety Advisory Panel Annual Report for 2018.
https://oiir.hq.nasa.gov/asap/documents/2018_ASAP_Report-TAGGED.pdf

- The Exploration Systems Development Program "*should clearly identify which systems or components must absolutely be present on EM-1* [Exploration Mission-1] *for them to be considered qualified for operation on EM-2. Crew risk mitigation on EM-2 depends on the flight demonstration of some elements of various systems. It is our position that those components, parts, or systems need to be directly identified by the Program and those essential elements be incorporated before the EM-1 flight is launched.*"
- Regarding preparations for the first integrated tests of the SLS and Orion vehicles, EM-1 and EM-2, the ASAP stated, *"The Environmental Control and Life Support System (ECLSS) is a principal EM-2 element that needs completion and qualification. The ASAP continues to be concerned about whether this system will be fully tested, qualified, and ready to support the crew launch for EM-2. Although NASA has informed the Panel about ECLSS testing, which is currently scheduled in 2021, we have not seen the plan for validation of the entire integrated system. While some components of the system are being operated on the ISS for microgravity experience, this component work does not substitute for integrated system operational validation.*"
- *"As NASA enters into new arrangements with commercial and international partners, we strongly suggest that an examination of the CCP* [Commercial Crew Program] *business model—as well as the lessons learned from the ISS—be taken into consideration. There will be tremendous value in understanding the complexities that are experienced in managing and mitigating risks that may be shared by multiple national and industrial partners.*"

Chairwoman HORN. This hearing will come to order.

Without objection, the Chair is authorized to declare recess at any time.

Good afternoon, and welcome to today's hearing entitled, "Keeping our Sights on Mars: A Review of NASA's Deep Space Exploration Programs and Lunar Proposal." I want to thank our witnesses for being here and thank you all for joining us.

So, today, we're examining NASA's deep space exploration programs—the capabilities and plans that will enable Americans to go beyond our low-Earth orbit neighborhood and into deep space. Successive NASA Authorization Acts have authorized a stepping-stone approach to human exploration, with the most recent, the *NASA Transition Authorization Act of 2017*, establishing Mars as the long-term goal. The law also directed NASA to prepare a human exploration roadmap.

In hearings from the last Congress to the present, Members of the Subcommittee and Full Committee have repeatedly asked for this roadmap, only to receive a response—in response a high-level strategy that was delivered over a year and a half late. I refer to this roadmap because, as the authorizing Committee, it is our responsibility to the American taxpayers to ensure that human space exploration plans and budget requests are based on sound analyses and clear goals and objectives.

We support NASA and we want it to succeed, so I am concerned that as we prepare to reauthorize NASA again, we have many unanswered questions about the future of our Nation's human space exploration program: How and when will we get to Mars? What technologies and systems are needed to get us there? What are the interim destinations and precursor missions that scientists and engineers have determined to be the most effective means to get us there? What is the future of the International Space Station (ISS), and what are the priorities to enable an eventual Mars mission? How long should it be operated, and what follow—and what will follow in low-Earth orbit?

Mars is the horizon goal, and I want Americans to be the first to set foot on the red planet. But make no mistake about it, there's an elephant in the room, and it's the Moon. In the absence of an integrated roadmap, the Administration decided that the Moon is the place to go with humans, that we should go there sustainably, and that—and be there permanently, though not necessarily with humans. And, as of just 6 weeks ago, the Vice President said that we need to get there fast, in 5 years rather than 9 years.

While I can't argue with the desire to invigorate our human exploration efforts and find near-term milestones to demonstrate success, the lack of planning evident so far, is no way to run our Nation's human space exploration program. The 2024 missive left NASA in a tizzy, scrambling to develop a plan and hastening to pull together a budget amendment that still has not been delivered to Congress, and upending groundwork with international partners on future exploration goals.

What are the primary goals and objectives for going to the Moon? Are they geopolitical, scientific, commercial, or as risk-reduction efforts for an eventual Mars mission? On which goal is NASA basing its architecture and mission decisions? Simply saying "yes" to all

of them is not an adequate way to determine our priorities. And how will we get there by 2024? NASA's solution? Get the private sector to do it and do it fast. Whether or not that will be through cost-plus or firm-fixed-price contracts, which are not typically used for development projects, whether or not contracts would involve a cost-sharing and at what level NASA oversight would be involved have not been made clear.

While public-private partnerships have a role to play, their use in human spaceflight programs has not yet been demonstrated. Commercial crew providers were awarded contracts in 2014 with an initial plan for certification by 2017. It's 2019, and while they're making good progress, we're still hitchhiking rides with the Russians to low-Earth orbit. Not only that, under those contracts, it's the companies, not NASA, that decide what information the public should be entitled to should something go wrong. We all know that spaceflight is risky, and things do go wrong. So let me be clear. I absolutely support America's robust, growing, and innovative space industry. A United States human space exploration program that leads the world should be leveraging private-sector innovation. The question is how.

At present, we have a White House directive to land humans on the Moon in 5 years but no plan and no budget details on how to do so and no integrated human space exploration roadmap laying out how we can best achieve the horizon goal, Mars. In essence, we're flying blind.

I'll close with this thought. I believe all of us—Republicans and Democrats alike—share the goal of a successful and ambitious human space exploration program that enables the United States, in concert with its international partners, to explore destinations in deep space such as the Moon and Mars. Such ambitious civil space goals are not only inspiring but essential to enabling discovery, providing benefits to society, and sustaining U.S. leadership in the peaceful uses of outer space.

The Space Exploration Initiative of 1989 and the 2004 Vision for Space Exploration were unfulfilled attempts to achieving deep space exploration goals to go to the Moon and Mars. Will our efforts this time be an opportunity lost or an opportunity gained? If they are to be an opportunity gained, we will need an integrated and stable plan, adequate and sustained resources, and a commitment that transcends political party and election timelines to get us there.

Thank you.

[The prepared statement of Chairwoman Horn follows:]

Good afternoon and welcome. I'd like to extend a special welcome to our witnesses. Thank you for being here.

Today, we're examining NASA's deep space exploration programs-the capabilities and plans that will enable Americans to go beyond our low-Earth orbit neighborhood and into deep space.

Successive NASA Authorization Acts have authorized a stepping-stone approach to human exploration, with the most recent-the NASA Transition Authorization Act of 2017-establishing Mars as the long-term goal. The law also directed NASA to prepare a Human Exploration Roadmap. In hearings from the last Congress to the present, Members of the Subcommittee and Full Committee have repeatedly asked for this Roadmap, only to receive in response a high-level strategy that was delivered over a year and a half late. I refer to this Roadmap, because as the Authorizing Committee, it is our responsibility to the American taxpayers to ensure that human

space exploration plans and budget requests are based on sound analyses and clear goals and objectives. We support NASA and we want it to succeed.

So I am concerned that as we prepare to reauthorize NASA again, we have many unanswered questions about the future of our nation's human space exploration program:

- How and when will we get to Mars?
- What technologies and systems are needed to get us there?
- What are the interim destinations and precursor missions that scientists and engineers have determined to be the most effective means to get us there?
- What is the future of the International Space Station and what are the priorities for it to enable an eventual Mars mission? How long should it be operated, and what will follow it in low-Earth orbit?

Mars is the horizon goal and I want Americans to be the first to set foot on the Red Planet. But make no mistake about it. There's an elephant in the room, and it's the Moon.

In the absence of an integrated Roadmap, the Administration has decided that the Moon is the place to go with humans, that we should go there sustainably, and be there permanently, though not necessarily with humans. And, as of just 6 weeks ago, the Vice President said we need to get there fast-in 5 rather than 9 years. While I can't argue with the desire to invigorate our human exploration efforts and find near-term milestones to demonstrate success, the lack of planning evident so far, is no way to run our nation's human space exploration program. The 2024 missive left NASA in a tizzy-scrambling to develop a plan and hastening to pull together a budget amendment that still have not been delivered to Congress; and, upending groundwork with international partners on future exploration goals.

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At present, we have a White House directive to land humans on the Moon in 5 years, but no plan or no budget details on how to do so, and no integrated Human Exploration Roadmap laying out how we can best achieve the horizon goal-Mars. In essence, we're flying blind.

I'll close with this thought. I believe all of us-Republicans and Democrats alike-share the goal of a successful and ambitious human space exploration program that enables the United States, in concert with international partners, to explore destinations in deep space such as the Moon and Mars. Such ambitious civil space goals are not only inspiring but essential to enabling discovery, providing benefits to society, and sustaining U.S. leadership in the peaceful uses of outer space. The Space Exploration Initiative of 1989 and the 2004 Vision for Space Exploration were unfulfilled attempts at achieving deep space exploration goals to go to the Moon and Mars. Will our efforts this time be an opportunity lost or an opportunity gained? If they are to be an opportunity gained, we will need an integrated and stable plan, adequate and sustained resources, and a commitment that transcends political party and election timelines to get us there.

Thank you.

Chairwoman HORN. All right. The Chair now recognizes Ranking Member Babin for an opening statement.

Mr. BABIN. Thank you, Madam Chair. We appreciate it. And I want to say thank you to all you witnesses that are here today. I'm looking forward to hearing your testimonies.

As this is the first formal hearing of the Space and Aeronautics Subcommittee of the 116th Congress, I would like to formally welcome you to the Committee, and I look forward to working with you, Chairwoman Horn, on one of the most exciting issues that we deal with here in Congress, and that is space exploration.

This is not only one of the most exciting issues, but it is also one of the most exciting times for space exploration. We have a renewed sense of urgency and purpose that is coupled with focus, leadership, and enthusiasm. I am excited to be involved in our Nation's space enterprise at this moment in our history.

We have a unique opportunity before us. We have an Administration that put forth a bold direction, and we have an agency that stands ready to meet that challenge. We've seen proposals to reinvigorate NASA before, but we are uniquely positioned at this moment to capitalize on the investments made over the last 2 decades.

Unlike President Kennedy's challenge to put a man on the Moon within the decade, we have already made the investments in the systems that will turn that challenge into a reality. And we now have robust centers and infrastructure, an eager workforce, a modern industrial base, a hungry commercial sector, a vibrant space market, and years of hardware development already under our belts. We are in the final stages of developing the Space Launch System (SLS). We've already conducted a test flight of the Orion capsule, and ground systems at the Kennedy Space Center are being built as we speak. The President has provided direction, focus, and enthusiasm, which will only help us in making continued progress.

And that isn't to say that we don't have work to do. Specifically, we need a clear plan and a realistic budget proposal. We need to be cautious about developing a plan that is overly ambitious or too costly, and we need to ensure that OMB sufficiently funds the plan in subsequent budget requests.

We must develop next-generation spacesuits and human-class landers, scale up in-space propulsion and life support systems, and properly mitigate radiation hazards. We must also develop these capabilities in an extensible manner that enables an evolvable architecture that can explore not only the Moon, but also Mars and beyond. And as the National Academy's Pathways to Exploration report recommended, NASA should develop technologies that feedforward from one mission to the next and reduce or eliminate the development of dead-end technologies.

Furthermore, Space Policy Directive 1 directed 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 new opportunities." Developing a plan that takes into account both the principles of extensibility and sustainability will be very challenging and will require NASA to make difficult decisions going forward, but I believe that NASA is well up to this task.

We must also be mindful of artificial schedule pressures. The Aerospace Safety Advisory Panel has noted in several reports that it's important to set challenging but achievable schedules and not allow undue schedule pressure to lead to decisions that adversely impact safety and mission assurance. Maintaining a balance be-

tween setting challenging yet achievable goals and taking prudent steps to ensure safe operations will certainly need to be addressed in any future plans.

Humanity will commit to the task of exploring the cosmos. The only real question is whether the United States will be the one to lead in that effort. I, for one, will do everything that I can to ensure that this happens.

Before I yield back my time, I would like to make one final observation. The Administration is still finalizing their lunar plans, and while this hearing is very helpful, and I realize that NASA previously committed to delivering a plan to the Committee by now, holding the hearing without new details does seem premature. I would respectfully recommend that we hear from NASA once this plan is finalized.

And so, with that, I'll yield back. Thank you.

[The prepared statement of Mr. Babin follows:]

Thank you, Chair Horn. As this is the first formal hearing of the Space and Aeronautics Subcommittee in the 116th Congress, I would like to formally welcome you to the Committee. I look forward to working with you on one of the most exciting issues we deal with here in Congress—space exploration.

This is not only one of the most exciting issues, but it is also one of the most exciting times for space exploration. We have a renewed sense of urgency and purpose that is couple with focus, leadership, and enthusiasm. I am excited to be involved in our nation's space enterprise at this moment in history.

We have a unique opportunity before us. We have an Administration that put forth a bold direction, and we have an agency that stands ready to meet that challenge. We've seen proposals to reinvigorate NASA before, but we are uniquely positioned at this moment to capitalize on the investments made over the last two decades.

Unlike President Kennedy's challenge to put a man on the Moon within the decade, we have already made the investments in the systems that will turn that challenge into reality. We now have robust centers and infrastructure, an eager workforce, a modern industrial base, a hungry commercial sector, a vibrant space market, and years of hardware development under our belt. We are in the final stages of developing the Space Launch System, we've already conducted a test flight of the Orion capsule, and ground systems at the Kennedy Space Center are being built as we speak. The President has provided direction, focus, and enthusiasm, which will only help us continue making progress.

That isn't to say that we don't have work to do. Specifically, we need a clear plan and a realistic budget proposal. We need to be cautious about developing a plan that is overly ambitious or costly, and we need to ensure that OMB sufficiently funds the plan in subsequent budget requests.

We must develop next generation space suits and human-class landers, scale-up in-space propulsion and life support systems, and properly mitigate radiation hazards. We must also develop these capabilities in an extensible manner that enables an evolvable architecture that can explore not only the Moon, but also Mars, and beyond. As the National Academy's "Pathways to Exploration" report recommended, NASA should develop technologies that feed-forward from one mission to the next and reduce or eliminate the development of "dead-end" technologies.

Furthermore, Space Policy Directive 1 directed NASA to "'[l]ead 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." Developing a plan that takes into account both the principles of extensibility and sustainability will be challenging and require NASA to make difficult decisions going forward, but I believe NASA is up to the task.

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Thank you.

Chairwoman HORN. Thank you very much. Dr. Babin, I appreciate that.

And the Chair now recognizes Chairwoman Johnson for her opening statement.

Chairwoman JOHNSON. Thank you very much, and good afternoon. I want to join the Chairwoman and Ranking Member in welcoming our witnesses to today's hearing, and I look forward to your testimony. I'll try to be brief in my remarks.

It is now more than 6 weeks since Vice President Pence announced that NASA was being directed by the President to undertake a crash program to land astronauts on the Moon within the next 5 years. Over that 6-week period, the President has been uncharacteristically silent, making no public statements or tweets in support of his lunar initiative.

NASA, for its part, has provided no specifics on either the plan or the required budget for the proposed accelerated Moon—well, this must be a sheet—I hope that when NASA delivers that plan and its revised budget to Congress, it will also provide a compelling rationale for the proposed crash program that justifies the additional resources that will be required to meet the President's arbitrary deadline. Because, as Chair of the Science Committee, I cannot look at NASA's proposal in isolation, nor can my colleagues on the Appropriations Committee.

I just came from a hearing on the National Science Foundation's (NSF's) Fiscal Year 2020 budget, where we heard that the President's request would cut NSF's budget by $1 billion. As you know, NSF is one of the Nation's premier research agencies, funding research across a range of important scientific disciplines. That billion-dollar cut will have serious negative impacts on major research areas if enacted.

A week ago, we had a hearing on the NOAA (National Oceanic and Atmospheric Administration) budget request, and the news was similar: The President's request would cut NOAA's budget by $1 billion. And 3 weeks before that, we heard that the President's request would cut the discretionary budget of the National Institute of Standards and Technology by more than 30 percent or almost $300 million. Finally, the Department of Energy's research programs would be cut by $4.5 billion. So if Congress is to increase NASA's budget simply to speed up a lunar landing relative to what was already planned, Congress will have to weigh the opportunity costs of doing so.

That said, I want to make it clear that I do not support the alternative of cannibalizing NASA's other important research activities just to speed up the human lunar exploration program.

On Monday, Ranking Member Lucas and I visited NASA's Goddard Space Flight Center and heard about all the important space

and Earth science research activities being undertaken there. We should be investing more in such inspiring and consequential research rather than cutting it, as is proposed in NASA's 2020 request.

As I close, I want to reiterate my support for a strong, forward-leaning human and robotic exploration program. I believe that human missions to the Moon and Mars, as well as robotic exploration, will continue to inspire, as it did when Americans first walked on the Moon. But we need to get it right as we pursue such a program, and we need to strike the right balance across all of our important national research priorities. Thus, I expect that this Committee will need to have NASA appear before us again once it provides us with the information it has promised.

And with that, I again want to welcome our witnesses, and I yield back.

[The prepared statement of Chairwoman Johnson follows:]

Good afternoon. I want to join the Chairwoman in welcoming our witnesses to today's hearing, and I look forward to your testimony.

I will be brief in my remarks. It is now more than six weeks since Vice President Pence announced that NASA was being directed by the President to undertake a crash program to land astronauts on the Moon within the next five years. Over that six week period, the President has been uncharacteristically silent, making no public statements or tweets in support of his lunar initiative. NASA, for its part, has provided no specifics on either the plan or the required budget for the proposed accelerated Moon program, saying it hopes to have something for Congress "soon".

I hope so. And I hope that when NASA delivers the plan and revised budget to Congress, it will also provide a compelling rationale for the proposed crash program that justifies the additional resources that will be required to meet the President's arbitrary deadline. Because as Chair of the Science Committee, I cannot look at NASA's proposal in isolation, nor can my colleagues on the appropriations committee.

I just came from a hearing on the National Science Foundation's FY 2020 budget, where we heard that the President's request would cut NSF's budget by a billion dollars. As you know, NSF is one of the nation's premier research agencies, funding research across a range of important scientific disciplines. That billion dollar cut will have serious negative impacts on major research areas if enacted. A week ago, we had a hearing on the NOAA budget request, and the news was similar: the President's request would cut NOAA's budget by a billion dollars. And three weeks before that, we heard that the President's request would cut the discretionary budget of the National Institute of Standards and Technology by more than 30 percent, or almost $300 million. Finally, the Department of Energy's research programs would be cut by $4.5 billion.

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With that, I again want to welcome our witnesses, and I yield back.

Chairwoman HORN. Thank you, Madam Chairwoman.

The Chair now recognizes Ranking Member and fellow Oklahoman Mr. Lucas.

Mr. LUCAS. Thank you, Chair, and fellow Okie.

Two days ago, I toured the Goddard Spaceflight Center with Chairwoman Johnson and Administrator Bridenstine and Director Scolese. The enthusiasm and focus of the NASA family is contagious.

And, as I said at our last hearing, our Nation's space program is a source of pride. It exemplifies the greatest aspects of our country: The pursuit of knowledge, heroism, technical excellence, perseverance, and the intrepid spirit to chart a course into the unknown. Exploration is in our DNA, and no other nation embraces that gift more than the United States.

NASA and this Administration are harnessing that gift and focusing our efforts to pioneer space. By continuing the investments made over the last 2 decades, we are progressing toward our national goal to send Americans to the Moon, Mars, and beyond.

The Vice President challenged the Nation to return astronauts to the Moon by 2024. It's an exciting and ambitious goal that will ultimately establish a long-term presence on the Moon, allowing us to explore its resources and conduct pioneering scientific research. I look forward to reviewing a proposal to achieve that goal. NASA, the Administration, Congress, the private sector, and ultimately the American people will all have a role to play in making that happen.

As we move forward, we would all benefit from remembering the lessons of previous proposals. The transition from Apollo to Shuttle, Space Station Freedom, the proposal to cancel the International Space Station program, the Space Exploration Initiative, the Vision for Space Exploration, the Constellation cancellation, and the Asteroid Retrieval Mission all provide unique lessons.

We should also realize that we can no longer take America's preeminence in space for granted. Other nations also have exploration plans. Urgency is now required to maintain our leadership.

NASA must provide a detailed plan for this next phase of exploration. The Administration and OMB (Office of Management and Budget) must provide a realistic funding proposal, and Congress must approve and appropriately fund the plan. This is not impossible, but it will require tough decisions, and, as Americans, we are up to that challenge.

And since this is our first hearing of this Subcommittee, Chair, I think there's a video that staff has that really kind of summarizes all this. I'd like to ask that the staff play a brief video in my remaining time.

[Video shown.]

Mr. LUCAS. Thank you, Madam Chairman. Sometimes we need to remember where we came from and where we are to be able to go forward. I yield back.

[The prepared statement of Mr. Lucas follows:]

Two days ago, I toured the Goddard Spaceflight Center with Chairwoman Johnson, Administrator Bridenstine, and Director Scolese. The enthusiasm and focus of the NASA family is contagious. As I said at our last hearing, our Nation's space program is a source of pride. It exemplifies the greatest aspects of our country: the pursuit of knowledge; heroism; technical excellence; perseverance; and the intrepid

spirit to chart a course into the unknown. Exploration is in our DNA, and no other nation embraces that gift more than the United States.

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NASA must provide a detailed plan for this next phase of exploration. The Administration and OMB must provide a realistic funding proposal. And Congress must approve and appropriately fund the plan. This is not impossible, but it will require tough decisions. As Americans, we are up to that challenge.

I'd like to now ask the staff to play a brief video for my remaining time, which captures the vision and work ahead for NASA.Thank you.

Chairwoman HORN. Thank you, Mr. Lucas. That was inspirational. I think it's clear that this Committee, there's a lot of agreement on both sides that we are fully in support, but we have some unanswered questions, and so I want to again thank the witnesses for being here today.

And at this time I'm going to begin with introduction and allow you all your opening statements.

Our first witness today is Mr. William Gerstenmaier, Associate Administrator for the Human Exploration and Operations Mission Directorate at NASA. Mr. Gerstenmaier provides strategic direction for all aspects of NASA's human exploration of space and cross-agency space support functions of the space communications and space launch vehicles.

Prior to his current position, Mr. Gerstenmaier served as the Manager for the International Space Station program. He also served as the Associate Administrator for the Space Operations Mission Directorate during the completion of the Space Station.

Mr. Gerstenmaier holds a bachelor of science in aeronautical engineering from Purdue University and a master of science degree in mechanical engineering from the University of Toledo. Welcome, Mr. Gerstenmaier.

OK. I apologize. I'm going to do the whole introductions and then I'll turn it over to you all.

Our second witness today is Mr. Mark Sirangelo, Special Assistant to the NASA Administrator, who is developing plans for deep space exploration. In this role, he will manage the programs to develop the Gateway, human-rated lander, and surface systems needed for a lunar program. Previously, Mr. Sirangelo headed Sierra Nevada Corporation's Space Systems, a producer of satellites, space transportation vehicles, propulsion systems, and space subsystems.

Mr. Sirangelo holds a bachelor of science and a master's of business administration and a doctorate. Welcome, Mr. Sirangelo. Thank you for being here today.

Our third witness is Dr. Patricia Sanders. We're going to go a little bit out of order from where you are. I promise, Dr. Lunine, I'll get back to you. I haven't forgotten about you.

Dr. Patricia Sanders, Chair of the Aerospace Safety Advisory Panel and an independent aerospace consultant. Previously, Dr. Sanders served as Executive Director of the Missile Defense Agency. She has also previously held positions in the Office of the Secretary of Defense, Air Force Operational Test Center, and the U.S. Space Command.

Dr. Sanders is a fellow of the American Institute of Aeronautics and Astronautics and has received the three Presidential Rank Awards for executive achievements.

Dr. Sanders received her doctorate in mathematics from Wayne State University. Welcome, Dr. Sanders. We're glad you're here.

Our fourth witness is Dr. Jonathan Lunine—see, I didn't forget—Director of the Cornell Center for Astrophysics and Planetary Science. Dr. Lunine is the David Baltimore Distinguished Visiting Science—Scientist at NASA's Jet Propulsion Laboratory. Dr. Lunine works on the Cassini mission and the James Webb Space Telescope and is a coinvestigator on the Juno mission. He is also a member of the National Academy of Sciences where he has been involved in numerous advisory and strategic planning committees, including Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration, which he co-chaired in 2014.

Dr. Lunine holds a bachelor's degree in physics and astronomy from the University of Rochester and a master's and doctorate degrees in planetary science from the California Institute of Technology. Welcome, Dr. Lunine.

And our fifth and final witness is Mr. Walter Faulconer, President of Faulconer Consulting Group, which provides strategic planning and business management services. Mr. Faulconer is currently a member of the NOAA Science Advisory Board and Executive Secretary for the Department of Defense Strategic Capabilities Office Advisory Group. He previously held the position of Director of Business Development for Space Transportation at Lockheed Martin. He also served as a Director of Strategic Planning and Development for Space Systems Company.

Mr. Faulconer holds a bachelor's from Florida Institute of Technology and master's degree from the University of Southern California. Welcome, Mr. Faulconer.

As our witnesses should know, you each have—will each have 5 minutes for your spoken testimony. Your written testimony will also be included in the record for the hearing. When you have completed your spoken testimony, we'll begin with questions. Each Member will have 5 minutes for questions. And we will start today with Mr. Gerstenmaier.

TESTIMONY OF MR. WILLIAM H. GERSTENMAIER, ASSOCIATE ADMINISTRATOR, HUMAN EXPLORATION AND OPERATIONS, NASA

Mr. GERSTENMAIER. Thank you very much for allowing me to testify on behalf of the NASA team. I think, as you saw on the video, this is an amazing time in human spaceflight.

We have more hardware in development than at any time in the history of NASA. There are three different capsule designs in work: Starliner, Dragon 2, and Orion. Multiple flight vehicles exist for each of these designs, and the purpose of the designs, either for low-Earth orbit or for deep space, are very different.

There's also a new winged commercial cargo vehicle also in work for the International Space Station. We also have a large heavy lift launch vehicle in work. The first launch vehicle core is scheduled for completion this year for further testing and assembly. The second launch vehicle core is also under construction. Today, you can go, see, and touch the vehicles that will return crews to the Moon and enable research and technology development that will allow us to go to Mars.

Further, we have an amazing international research facility in low-Earth orbit. We've had crews in space continuously since October 2000, almost 19 years. The International Space Station is allowing commercial industry to experiment with revenue concepts in low-Earth orbit, NASA to test the next generation of life support systems, NASA to understand how to keep crews healthy for long durations in deep space, and perform fundamental research in a variety of fields. All of this ISS research ultimately supports improving life here on Earth.

With all this activity and work, there's a new excitement in the space workforce. It is very timely and fitting today that we have this hearing entitled, "Keeping Our Sights on Mars: A Review of NASA's Deep Space Exploration Programs and Lunar Proposal." Ultimately, all of these hardware development efforts are tied together, and they all support building systems that will allow us to move human presence into the solar system. By taking the long view, we can keep the individual activities linked. We do not have time or funds to build unique one-of-a-kind systems. We need to build systems that can improve technical knowledge and can be used to support multiple objectives.

The challenge of Mars with humans is large and requires all of us with commercial industry, universities, the public, international partners to work together to make this goal a reality. Interoperability standards being developed such as the international docking standard will allow all to participate in this goal.

Recently, we were challenged to return to the surface of the Moon with humans in 2024. Having a sense of real urgency is critical. This can help focus our efforts and create a framework for timely decisions. Keeping the long view but creating the urgency for near-term objectives can create a strong framework for us to work together.

NASA's building off the systems already in work, as mentioned earlier. We will select partners to develop the first element of Gateway, the power and propulsion element, by this summer. We will select partners to begin studying the lunar descent systems, transfer vehicles, and investigate refueling options. We have a synopsis out for review of the human lunar lander system. All—some of these systems for the Moon such as the ascent vehicle can be used for Mars. The transfer vehicles and power systems all have applications toward Mars.

Learning to operate reusable systems at Gateway and navigate around the Moon are all helping us to learn how to keep crews safe on journeys toward Mars. The Gateway itself can help us to understand Mars transit vehicle requirements. The Moon is a great proving ground, a great place to learn for deep space systems that are necessary for Mars.

We are taking the next generation of space engineers, and we are training them for the future. The risk and challenges are huge, but so are the gains. The challenges that we face all help to improve life here on Earth. The recycling systems on ISS needed for deep space travel have applications here on Earth. We must never think that tests or operations are easy or routine. We will stay vigilant with a sense of urgency. We will look forward to continuing to work with this Committee to achieve amazing things in space.

This Committee has been tremendously supportive in the past and often asks for concrete plans for human exploration. We are ready to finalize those plans and work together with a sense of urgency. Working together, we can accomplish amazing things.

I look forward to your questions and to the dialog.

[The prepared statement of Mr. Gerstenmaier and Mr. Sirangelo follows:]

HOLD FOR RELEASE
UNTIL PRESENTED
BY WITNESS
May 8, 2019

Statement of

William H. Gerstenmaier
Associate Administrator for Human Exploration and Operations
National Aeronautics and Space Administration

and

Mark Sirangelo
Special Assistant to the Administrator
National Aeronautics and Space Administration

before the
Committee on Science, Space, and Technology
Subcommittee on Space and Aeronautics
U.S. House of Representatives

Overview

Chair Horn and Members of the Committee, we are pleased to have this opportunity to discuss the latest developments in the NASA Exploration Campaign. Space Policy Directive-1 (SPD-1) directs the NASA Administrator 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. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term, sustainable exploration and utilization, followed by human missions to Mars and other destinations." Our pursuit of these objectives will enable America to achieve strategic presence on the Moon and preeminence in cislunar space. NASA has laid out a clear plan for NASA's Exploration Campaign that cuts across three strategic areas: low Earth Orbit (LEO), the Moon, and Mars and beyond.

Exploring the Moon strengthens American leadership in science, exploration, technology and innovation, and provides a chance for an economic revolution:

- Just as Apollo inspired a generation, NASA continues to inspire with feats of science and exploration today. If we bring together the capabilities and resources of our international and commercial partners to return to the Moon and continue to Mars, we will demonstrate to young people around the world the power of a unified purpose – an example of what humankind can do when it comes together to achieve a common goal for the common good.

- The Moon is a treasure chest of science and knowledge we can acquire with a sustained human and robotic presence. The lunar samples returned during the Apollo Program dramatically changed our view of the solar system, and scientists continue to unlock new secrets from the samples. We believe the poles of the Moon hold millions of tons of water ice. The farther

humans venture into space, the more important it becomes to manufacture materials and products with local resources. We know the Moon can tell us more about our own planet, and even our own sun.

- Exploration is critical to the continuation of our species. Humanity must build a pathway to enable settlements beyond Earth, and the Moon is a testbed for Mars. It provides an opportunity to demonstrate new technologies that we will use on crewed Mars missions: power and propulsion systems, human habitats, in-space manufacturing, life support systems, *in situ* resource utilization. Just as important, it provides a nearby opportunity to test new approaches to designing our programs so that we can cost-effectively, expeditiously, and safely expand the envelope of human activity in the solar system.

- We're laying the groundwork for the next economic revolution – a revolution which will happen in space, built on mining, tourism, and scientific research that will power and empower countless future generations and create new jobs and industries. Our investments in revolutionary, American-made technologies today fuel tomorrow's innovation and space economy.

We are pursuing the goals established by SPD-1 and the NASA Transition Authorization Act of 2017 with a new sense of urgency. We are going to land the first woman and the next man on the Moon near the South Pole by 2024. The architecture to support human landings on the Moon in 2024 is based on the architecture already in development to support our previous goal to land on the Moon in 2028. The landing in 2024 will use the Space Launch System (SLS) and Orion crew vehicle already being developed as the backbone of our deep space exploration architecture. NASA is now engaged in intensive discussions and analysis to produce the resource estimates and detailed schedules that will support the 2024 landing. Our initial focus will be on speed, working toward long-term sustainability and continuously expanding on the broader commercial, science, academia and international partnerships that will support our horizon goal: human missions to Mars.

PHASE 1: Moon to Mars (M2M): 2024 – A New Urgency

NASA is going forward to the Moon. 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 the first American astronauts return to the lunar surface, they will take their first steps on the Moon's South Pole. NASA is developing a plan to accomplish this charge and will submit a FY 2020 Budget Amendment in the near future for necessary expenses to accelerate activities to establish a United States presence on the Moon by 2024. Our goal is to leverage and build upon our existing work and plans to achieve these new goals.

Schedule performance by SLS and Orion are critical to achieving a human return to the Moon by 2024. In early March, the Human Exploration and Operations Mission Directorate (HEOMD) chartered an assessment to evaluate alternate approaches for hardware processing and facilities utilization for key components, with the goal of maintaining an early as possible EM-1 launch date. To date the following has been concluded:

- The 45-day study identified production and operations opportunities that help offset schedule delays for EM-1 while identifying minimal change to the risk posture.

- An alternate assembly plan has been adopted to assemble the entire Core Stage in parallel with the engine section, then mate the engine section horizontally. Vertical final outfitting will occur at Stennis Space Center. This alternate assembly approach will result in reducing the time the vehicle will be at Michoud Assembly Facility by approximately 3.5 months.

- Orion will remove propellant and consumables not needed for the EM-1 mission; this reduction in Orion mass will provide up to three days of additional launch window opportunities.

- Even with the changes described above, it will not be possible to meet the previously-planned EM-1 launch target of no earlier than (NET) June 2020. NASA and its contractors are working to address the programs' performance issues and prevent further delays.

Next, an independent schedule risk review led by the NASA Office of the Chief Financial Officer will evaluate the HEOMD assessment and build on it to include the integrated, detailed schedule and associated risk factors ahead of EM-1. NASA leadership will review the results of these assessments in late spring 2019 at an Agency Program Management Council, before revisiting the EM-1 and EM-2 launch planning dates.

The EM-1 schedule is important, but using EM-1 to discover early design problems is more important. Launching EM-1 early and missing key tests could delay our overall objective for 2024. A successful lunar campaign is a series of missions and not an individual flight. EM-1 will be followed in 2022 by EM-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 2024. We will continually assess commercial options for later missions. 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.

A second component of our exploration architecture is the Gateway. The Gateway will function as a mobile base camp from which NASA, its international partners, and its commercial partners, can mount robotic and human expeditions to and around the Moon. Given the urgency of the 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 element. Both of these modules will be launched on commercial launch vehicles. Future Gateway elements will be focused on sustainability, with new capabilities added incrementally as needed.

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. NASA previously planned to release a solicitation for an ascent module, but in response to the acceleration of the HLS to 2024, we updated our plans and will seek proposals from U.S. industry in support of rapid development, integration, and crewed demonstration of the Lander elements as a functional human landing system that can fulfill NASA and industry requirements for 2024. Using this approach will enable rapid development and flight demonstrations of human lunar landers.

NASA has proposed establishment of a new Moon to Mars Mission Directorate, which will manage systems development and technology investments for programs critical to the Agency's Exploration Campaign in an integrated manner, including all key lunar and cislunar activities as well as all technology development and demonstration activities.

Exploration Campaign

Based on the objectives in SPD-1, the *National Space Exploration Campaign Report*, submitted to Congress in September 2018, laid out five strategic goals for NASA's near-term exploration:

1. Transition U.S. human spaceflight in LEO to commercial operations that support NASA and the needs of an emerging commercial economy;
2. Lead the emplacement of capabilities that support lunar surface operations and facilitate missions beyond cislunar space;
3. Foster scientific discovery and characterization of lunar resources through a series of robotic missions;
4. Return U.S. astronauts to the surface of the Moon for a sustained campaign of exploration and utilization; and
5. Demonstrate on the Moon the capabilities required for human missions to Mars and other destinations.

The Exploration Campaign leverages a diverse array of human and robotic assets. It builds on more than 18 years of Americans and our international partners living and working continuously on the International Space Station (ISS). It leverages the advances made in commercial launch vehicle capabilities, robotics, and other technologies. With the launch of the Orion capsule and SLS rocket, as well as supporting launches of commercial rockets, NASA will expand human exploration to cislunar space and the surface of the Moon. As part of the Campaign, we also will begin sending increasingly capable robotic missions to the lunar surface in the next two years. Developed by U.S. commercial companies, these spacecraft will conduct scientific investigations, characterize resources, and provide lunar landing services to customers from America and around the world. We will also continue to execute sophisticated robotic missions to Mars while we work to develop and demonstrate the deep space capabilities required to safely send a human crew to the Red Planet.

Activities across the LEO, Moon and Mars domains are closely related and mutually supportive. For example, NASA's drive to conduct robotic and human exploration of the Moon informs the research and technology development we will conduct on the ISS and potential future orbital platforms, as well as the development of technologies needed for future Mars missions. Likewise, current and future robotic missions will provide vital science, reconnaissance, and technology demonstrations in support of future human exploration, in addition to their science objectives. NASA is actively working now to support sustainable exploration and development over the coming decades in all three domains.

ISS and LEO Commercialization

NASA is working to expand Government and commercial access to space, and to lay the foundation to support future commercial operations in LEO. These activities support existing and future space operations, commercialization, and space and flight support capabilities for NASA and non-NASA missions.

NASA's industry partners are routinely launching and returning cargo to and from Earth, and NASA is building upon that partnership with commercial crew launches to and from the ISS.

NASA will continue its mission in LEO with the ISS to enable exploration with humans to the Moon and on to Mars, continuing to perform research that benefits humanity, supporting National Lab research by private industry and other organizations, and working towards reducing operations and maintenance costs. The Commercial LEO Development effort is providing resources for NASA to assist industry in

developing a commercial LEO presence, with and without crews. As these new commercial capabilities are deployed in orbit, NASA will transition its LEO activities to employ them. Together, NASA's ISS and Commercial LEO Development efforts will lay the foundation for a future in which NASA is one of many customers of an industry-led human spaceflight enterprise.

Exploration Technology

Exploration Technology funds critical technology development to enable the Exploration Campaign, including high-power solar electric propulsion, precision landing, and cryogenic fluid management and transfer. Research and development of new technologies and capabilities lay the groundwork for enhancing and enabling lunar and deep space exploration. Exploration Technology also funds the Lunar Surface Innovation Initiative as well as technology research and development projects along the entire Technology Readiness Level spectrum that align with NASA exploration needs and support commercial expansion in space. The Lunar Surface Innovation Initiative serves as a catalyst for lunar surface technology development priorities such as: surface power, *in situ* resource utilization (ISRU), autonomous operations, and extreme environment technology. NASA is implementing this initiative by embracing competition and partnerships with industry, universities, and other Government agencies. Exploration Technology will enable NASA's workforce, in concert with industry and academia, to focus on innovative ways to further humankind's space activities from conception to testing to spaceflight.

Scientific Exploration

NASA's Science Mission Directorate (SMD) will continue its efforts to explore and enhance scientific discovery. In the context of the Exploration Campaign, this includes the Lunar Development & Exploration Program (LDEP) and the Mars Sample Return mission. NASA intends to also work with international and commercial partners in these endeavors, delivering meaningful scientific exploration and technology development work in a cost-effective way.

NASA is developing a series of instruments, experiments, and other payloads for robotic precursor lunar missions to the surface of the Moon, utilizing innovative acquisition approaches to engage U.S. industry capabilities as the Agency moves toward human exploration of the lunar surface. In November 2018, NASA selected nine companies as part of the Commercial Lunar Payload Services (CLPS) procurement, making them eligible to provide transportation services to the lunar surface for science, technology, and exploration payloads. In February 2019, NASA selected thirteen NASA-provided payloads that could be flown on the early CLPS missions. Last week, NASA received proposals from the CLPS providers for the first commercial delivery service to transport some of these payloads to the lunar surface. This ground-breaking service will be awarded later this month, leading the way for America's return to the surface. These missions will enable new science and demonstrate new technologies supporting sustainable human return to the lunar surface.

NASA will advance robotic access to Mars in preparation for human exploration. The Agency will continue to execute sophisticated robotic missions to Mars while we work to develop and demonstrate the deep space capabilities required to safely send a human crew to the Red Planet (e.g., demonstrate technology to produce oxygen from Mars resources, critical for future human Mars missions). This will include continuing the search for life with the Mars 2020 rover, and a Mars Sample Return mission launching from Earth as early as 2026.

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 in all three human spaceflight domains. Through reduction in costs, the Agency can invest in future deep space capabilities and use the 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 a human exploration mission 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 occupied like the ISS. NASA currently envisions crew visits approximately once per year, so a strong focus is placed on robotic activities and infrastructure to foster ongoing investigations and operations that can operate autonomously between crew visits.

NASA's access to the Moon and its resources must be sustainable over the long haul. This does not require a permanent human presence around or on the Moon, but it does require the ability to cost-effectively access the Moon, conduct a variety of operations on or near the Moon, and return safely to Earth as requirements dictate and opportunities arise. Therefore, we will enhance Gateway's capabilities with our international and commercial partners with the goal of making lunar presence and activities sustainable. Future investments in the Gateway would contribute to lunar sustainability by enhancing resupply and the ability to conduct extended uncrewed operations and, using its solar-electric PPE, allowing us to access more regions and science opportunities on the Moon than ever before. In a Near-Rectilinear Halo Orbit around the Moon, we will have constant communications with the Earth, benign thermal effects, and the ability to abort from the surface of the Moon to the Gateway. While minimal at first, over time the Gateway will provide opportunities to conduct broad scientific research.

Gateway will be followed by other assets that would enable sustainability, such as reusable landers, reusable tugs, 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 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.

Conclusion

NASA's Exploration Campaign will create an architecture that is open, sustainable, and agile across LEO, the Moon and Mars. This year, the SLS and Orion, critical components of our exploration architecture, will reach important milestones in construction and testing as the program works through development challenges. We have called on American companies to help design and develop human lunar servives for

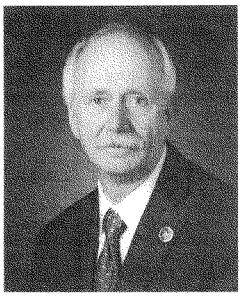
surface activities. We will continue to build commercial and international partnerships into our Gateway and lunar surface concepts to promote sustainable exploration. We are advancing our scientific knowledge and technology development with our partners through robotic precursors on the Moon and Mars. In LEO, our Commercial Crew Program continues to take strides and will soon be delivering American astronauts, on American rockets, from American soil to the ISS for the first time since 2011.

Through these activities, NASA's will realize exploration opportunities in the near-term, achieve strategic presence on the Moon and preeminence in cislunar space, and continue American space leadership for decades to come. This will empower American global leadership, spur innovation, and expand economic growth.

There's a lot of excitement about our plans and also a lot of hard work and challenges ahead, but we know the NASA workforce and our partners are up to it. The Agency is ready for the challenge of moving forward to the Moon – this time to stay. We will work to ensure that the United States quickly, safely, and cost-effectively attains our goals for 2024 and beyond.

Thank you for the opportunity to testify before you today and we look forward to answering your questions.

William H. Gerstenmaier, Associate Administrator, Human Exploration and Operations



William H. Gerstenmaier is the associate administrator for the Human Exploration and Operations Mission Directorate at NASA Headquarters in Washington. In this position, Gerstenmaier provides strategic direction for all aspects of NASA's human exploration of space and cross-agency space support functions of space communications and space launch vehicles. He provides programmatic direction for the operation and utilization of the International Space Station and its crew; development of the Gateway, Space Launch System and Orion spacecraft; and is providing strategic guidance and direction for the commercial crew and cargo programs. Working with commercial and international partners, NASA will lead a sustainable return to the surface of the Moon.

Gerstenmaier began his NASA career in 1977 at the then Lewis Research Center in Cleveland, performing aeronautical research. He was involved with the wind tunnel tests that were used to develop the calibration curves for the air data probes used during entry on the Space Shuttle.

Beginning in 1988, Gerstenmaier headed the Orbital Maneuvering Vehicle (OMV) Operations Office, Systems Division at the Johnson Space Center. He was responsible for all aspects of OMV operations at Johnson, including development of a ground control center and training facility for OMV, operations support to vehicle development, and personnel and procedures development to support OMV operations. Subsequently he headed the Space Shuttle/Space Station Freedom Assembly Operations Office, Operations Division. He was responsible for resolving technical assembly issues and developing assembly strategies.

Gerstenmaier also served as Shuttle/Mir Program operations manager. In this role, he was the primary interface to the Russian Space Agency for operational issues, negotiating all protocols used in support of operations during the Shuttle/Mir missions. In addition, he supported NASA 2 operations in Russia, from January through September 1996 including responsibility for daily activities, as well as the health and safety of the NASA crewmember on space station Mir. He scheduled science activities, public affairs activities, monitored Mir systems, and communicated with the NASA astronaut on Mir.

In 1998, Gerstenmaier was named manager, Space Shuttle Program Integration, responsible for the overall management, integration, and operations of the Space Shuttle Program. This included development and operations of all Space Shuttle elements, including the orbiter, external tank, solid rocket boosters, and Space Shuttle main engines, as well as the facilities required to support ground processing and flight operations.

In December 2000, Gerstenmaier was named deputy manager, ISS Program, and two years later became manager. He was responsible for the day-to-day management, development, integration, and operation of the space station. This included the design, manufacturing, testing, and delivery of complex space flight hardware and software, and for its integration with the elements from international partners into a fully functional and operating space station.

Named associate administrator for the Space Operations Directorate in 2005, Gerstenmaier directed the safe completion of the last 21 Space Shuttle missions that witnessed assembly completion of the International Space Station. During this time, he provided programmatic direction for the integration and operation of the ISS, space communications, and space launch vehicles.

Gerstenmaier received a Bachelor of Science in aeronautical engineering from Purdue University in 1977 and a Master of Science degree in mechanical engineering from the University of Toledo in 1981. He completed course work early in his career for a doctorate in dynamics and control with emphasis in propulsion at Purdue University, and in spring 2019, he will receive an honorary doctorate from his alma mater.

For his technical contributions and leadership in national and international human spaceflight programs, Gerstenmaier was elected into the 2018 class of the National Academy of Engineering.

Gerstenmaier is the recipient of numerous awards, including three NASA Certificates of Commendation, two NASA Exceptional Service Medals, a Senior NASA Outstanding Leadership Medal, the Meritorious Executive Presidential Rank Award, and Distinguish Executive Presidential Rank Award. He also was honored with an Outstanding Aerospace Engineer Award from Purdue University. Additionally, he was twice honored by Aviation Week and Space Technology for outstanding achievement in the field of space. His other awards include: the AIAA International Cooperation Award; the National Space Club Astronautics Engineer Award; National Space Club Von Braun Award; the Federation of Galaxy Explorers Space Leadership Award; AIAA International Award; the AIAA Fellow; Purdue University Distinguished Alumni Award; and honored at Purdue as an Old Master in the Old Masters Program; recipient of the Rotary National Award for Space Achievement's National Space Trophy; Space Transportation Leadership Award; the AIAA von Braun Award for Excellence in Space Program Management; and the AIAA von Karman Lectureship in Astronautics.

He is married to the former Marsha Ann Johnson. They have two children.

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Mark N. Sirangelo
Special Assistant to the Administrator

Mark N. Sirangelo has a long history in space and aerospace having lead program teams that participated in over 300 space missions, including over 20 planetary missions and 70 NASA missions. His recent work experience has been as Scholar in Residence for Engineering, Applied Science and Aerospace at the University of Colorado. Formerly, he was the head of Sierra Nevada Corporation's Space Systems and CEO of SpaceDev, its predecessor company. He also served on the Defense Innovation Board for the Secretary of Defense and as the Chief Innovation Officer of the State of Colorado.

His personal and organizational recognitions include being inducted into the Space Foundation's Technology Hall of Fame, being an Associate Fellow of the American Institute of Aeronautics and Astronautics, named as one of the World's Top 10 Innovative Space Companies by Fast Company, and recognized as Manufacturer Builder of the Year by ColoradoBiz, The Best Place to Work by the Business Journals, and part of Inc. Magazine's top 200 companies. Mr. Sirangelo was a founding member of the Commercial Spaceflight Federation and the founder and Chairman of eSpace, the Center for Space Entrepreneurship. He has been working to make the world a safer place for children as a foundational Board member of the National Center for Missing and Exploited Children. He holds Doctorate, MBA and Bachelor of Science degrees, is a long-term licensed pilot, and has served his country proudly as a U.S. Army officer.

Chairwoman HORN. Thank you, Mr. Gerstenmaier.
Mr. Sirangelo.

TESTIMONY OF MR. MARK SIRANGELO,
SPECIAL ASSISTANT TO THE ADMINISTRATOR, NASA

Mr. SIRANGELO. Good afternoon. Thank you for having me.

It's really an amazing time to be able to come here and talk about America's deep space program. It's been 50 years since we first went to the Moon and 47 years since we've been back. I believe it's time we take another step. That step will be the first on a renewal that we will have not only to the Moon but to Mars and beyond, and from NASA's perspective the next step will be taken by the first American woman on the Moon.

We will return to the Moon this time not just to visit but to stay. After building on our success in low-Earth orbit, we'll be combining the expertise of NASA, along with our commercial partners, our universities, our laboratories, and our international partners to develop the exploration capabilities we'll need and the architecture that will get us back to the lunar surface as safely and as quickly as possible.

But there's more to that. We will create new jobs. We will create new economic opportunities. We will motivate generations of young people. The science and technology we'll develop along the way will improve our life on Earth.

Even though our eyes are on 2024, we're not beginning there. This year, coming up in the next few months, we will start with a small series of commercial robotic missions—precursor missions, we call them—to the Moon. We will use these landers and robots and technology to conduct science across the lunar surface.

Throughout my long history in the space industry, I've been fortunate to lead teams that have participated in hundreds of space missions, including missions to multiple planets, asteroid, the sun, and of course the Moon. Whenever I get asked questions, most of the time I get asked about the shiny spaceships or the rockets or the technology, and that's a wonderful thing to do, and as a technologist, as a builder, it's a—it is wonderful to talk about those.

But today, I'm here is a futurist and now as a proud new member of the NASA team and as an American. I want to put the technologies aside and talk a little bit about the why. Why go back to the Moon? Why now? Why this expedited effort? Why America? Just as Apollo inspired previous generations, NASA today is uniquely positioned to continue that inspiration to inspire the future generations, we already work with over 60 universities and have created thousands of internships which have turned—sparked thousands of dreams, but we're not satisfied. There's more that we can do.

By bringing the capabilities of our country together to return to the Moon and on to Mars we'll demonstrate to the young people of this country and around the world the power of dreaming big. We hope to create an unparalleled example that humankind can do when it comes together to do an uncommon task for the common good.

These next generations may or may not take the power of this lesson to space or to the space industry, but they will take them

somewhere. In my view, the biggest legacy of the Apollo program was not the rocks that we brought back but it was the people that we inspired, generations of those people, some sitting in this room today that went on to make America a better place.

The Moon is a treasure chest of science. The lunar samples returned by the Apollo program dramatically changed our view, but it's just the beginning. We believe the South Pole, which is our first destination, holds millions of tons of water ice. That ice represents power, it represents fuel, it represents scientific discoveries. As we go further into space, it's going to become even more necessary for us to learn how to live in space without the connection to Earth. We need to learn to do this, and the Moon is a good place to make it happen.

As was said earlier today, the exploration is in our DNA. The ability for humans to want to go to places we haven't been has been around as long as humans have been around not only through the oceans, underneath the oceans, across the lands, but now into vast regions of space. It's really part of our psychological makeup. But more importantly, it fuels our soul. You don't have to go any further than just see the faces of the young kids who come to visit NASA or to know that the Air and Space Museum is the most visited museum in the world.

We believe the Moon is a test bed, a test bed for learning and a test bed for Mars that provides opportunities to demonstrate new technologies that are necessary for those missions. But along this path we're also going to be creating a new revolution, an economic revolution. Generations past had the Industrial Revolution, the computing revolution, the internet revolution, all of which helped make the U.S. a leader in the world. The next revolution in our view is going to be happening in space.

Finally, as we approach this Memorial Day, I'd like to take a moment to reflect on all those who have given their lives for us, and today, everywhere in the world, they're standing watch for us. If you ask those people who are doing that why they're doing it, most of them will say to protect their families, to protect their homes, to protect their country, and I think one more thing they'd say is to protect the American way of life. As part of that, I believe that American way of life not only has all the things that we live for and exist every day, but it's also an important part to understand that it gives us the chance to dream, to dream big, and to chase those dreams. I know I had this chance, and it brought me to this hearing and gave me a chance to touch the stars, and we want to make that happen for a lot of other young people in the world.

Even now, 50 years later, people around the world would point to the Apollo landings as one of the most important things that we've ever done, and we think it is, but we think the way to honor those people who have been part of that Apollo program is to not only look at those grainy videos and pictures but to create new high-definition views of the future. Thank you very much.

Chairwoman HORN. Thank you, Mr. Sirangelo.

Dr. Sanders.

TESTIMONY OF DR. PATRICIA SANDERS, CHAIR, AEROSPACE SAFETY ADVISORY PANEL

Dr. SANDERS. Chairman Horn and Members of the Committee, thank you for the opportunity to discuss NASA's deep space exploration program.

A principal role of my panel is advising NASA and the Congress on the safety and risk of human spaceflight. I emphasize that our responsibility is to provide advice driving down risk to the lowest level consistent with accomplishing the mission. Space exploration is inherently dangerous. The environment is hostile; the systems needed to survive in it are complex. The aim is not to avoid risk at all costs but manage the risk intelligently.

Over the—our advice over the years has had consistent themes. One, as Representative Babin has quoted, is the importance of setting challenging but achievable schedules and not allowing undue schedule pressure lead to decisions adversely impacting safety and mission assurance. A second is addressing the question of how safe is safe enough within the context of the overall risk-benefit equation. The third is the importance of constancy of purpose, and fourth, holding to the fundamentals of risk management or recognizing that no single approach dictates the success of such an approach. I'll speak briefly to each of them in the context of the current programs.

The Administration's policy of the—is to return astronauts to the Moon within the next 5 years, adding urgency to a complex and ambitious endeavor. Our panel continues to caution that targeted launch dates, while useful to impart a sense of urgency, should be used judiciously. Unrealistic schedules can result in poor decisions at least from a safety perspective if they lead to unwise shortcuts or elimination of critical testing.

For example, we know that NASA is exploring options for launching Exploration Mission (EM) 1 as early as possible. This could have positive results, perhaps achieve greater decision velocity, restructured and more efficient work flow, a more streamlined approach. But we should not forget that the ultimate purpose of that flight is to mitigate risk and understand operational margins prior to the first crewed flight. Critical data is required to ensure as much as possible a safe EM-2 mission, including a successful green run, an effective heatshield, effective operation of parachute systems, abort mechanisms, and environmental control and life-support systems, among other things.

In addressing safety in human space exploration, balancing the risk with value is important. It's paramount. As Congresswoman Horn had said, NASA's role in advancing space exploration pushes the envelope with great uncertainties and inherent risks, but safe as a term in this context does not have the same connotation as in a typical day-to-day life. With no excuse for negligence, it is impossible to control, eliminate, or mitigate every risk. So determining an acceptable level of risk balances many factors to decide if the chance of a mishap is outweighed by the likely mission benefit. Return to the Moon should not be an end in and of itself but considered in a risk-value framework.

We should ask, as she has, is the objective—what is the objective of the mission? Is it part of a cohesive long-term strategy? Will it

buy down risk for future exploration? Will it provide infrastructure-enabling next steps? Does it further the national goal of commercial space self-sufficiency? Does it support national leadership and foster international cooperation? Great exploration has involved major risk whether it was Magellan or Lewis and Clark, but it has been undertaken with an expectation of great benefits.

Hand-in-hand with the risk-value proposition is constancy of purpose, national steadfastness, and pursuing stated goals that do not waiver over time and a willingness to support those goals with the necessary resources. Fluctuating policy, ambiguous objectives, budget inadequacies, and uncertainties add complexity and inefficiency to program management. They detract from meeting technical goals, and they dilute focus on safety and mission assurance.

Last, as NASA embarks on the next phase of space exploration, I encourage them, in partnership with the Congress, to sustain the foundational standards of risk management while embracing new approaches. To that end, we can learn from and expand on the positive aspects of the experience with the Commercial Crew Program. We evolved there over time, and the establishment of mutual trust and transparency, the use of "badgeless" teams, early engagement, and appropriate engagement of the government, appropriate contract flexibility, and timely decisionmaking. These bring the potential to not only lower cost and shorten development time but also to reduce risk.

In closing, I note that NASA and the Nation have made great progress in the last few years, but a lot of work remains ahead. It is a time for excitement, optimism, and reasoned caution.

Thank you. I look forward to your questions.

[The prepared statement of Dr. Sanders follows:]

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May 8. 2019

Statement of
Dr. Patricia Sanders
Chair
National Aeronautics and Space Administration's
Aerospace Safety and Advisory Panel

Before the

Subcommittee on Space and Aeronautics
Committee on Science, Space and Technology
U.S. House of Representatives

Chairwoman Horn and Members of the Subcommittee, thank you for the opportunity to appear before you today to discuss NASA's deep space exploration programs, including proposed lunar activities.

As you know, the Panel I chair is charged with advising both the NASA Administrator and the Congress with respect to the safety and risk of human space flight among other aspects of safety. In opening, I would like to emphasize that the Panel feels the responsibility to provide advice in such a way as to promote driving down risk to the lowest reasonable level consistent with accomplishing the mission. Space exploration is inherently dangerous. The environment is hostile and the systems needed to survive in it are complex. Our charge is not to avoid that risk at all costs, but to manage that risk intelligently.

Our advice and recommendations over the years has included some consistent themes:

- A key one, repeated year after year, is the importance of setting challenging, but achievable schedules and not allowing undue schedule pressure to lead to decisions that adversely impact safety and mission assurance.

- Secondly, is that the question of "how safe is safe enough" cannot be addressed without consideration of the overall risk-benefit equation.

- Thirdly, we have consistently maintained that mission success requires a constancy of purpose, a sustained commitment and a clear understanding of objectives.

- And, we have continuously maintained that while NASA should never lose sight of the fundamentals in risk management for successful program execution, there is no one approach that dictates that success and there should be an openness to learning and accepting alternative means to understand and control margins.

I will speak briefly to each of these principles in the context of the current programs, including proposed lunar activities and the long-term goal of sending humans to the surface of Mars.

The Administration has announced that its stated policy, and that of the United States, is to return astronauts to the Moon within the next five years. This declaration has added an urgency and vibrancy to an already complex and ambitious endeavor. But as NASA prepares to meet this exciting, but clearly aggressive goal, our Panel continues to caution that targeted launch dates, while useful to impart a sense of urgency and to convey the importance of holding to the planned schedule, should be used judiciously. It can be detrimental to employee morale if the official dates are clearly not achievable, given the work that needs to be accomplished. Unrealistic schedules can also result in poor decisions, at least from a safety perspective, if meeting these deadlines results in imprudent shortcuts, or elimination of important testing.

For example, the Panel has been aware that NASA has been exploring options for launching Exploration Mission One (EM-1) as early as possible. This examination will no doubt result in some useful approaches – perhaps achieving greater decision velocity, restructured and more efficient work flow, and a more streamlined approach. But as plans go forward for EM-1, we should not lose sight of the fact that the ultimate objective of that flight is to mitigate risk and understand the operational margins prior to the first crewed flight. There are several critical data sets that are required to ensure, as much as possible, a safe EM-2 mission, such as a successful Green Run, an effective heat shield, effective operation of the parachute systems, the abort mechanisms, and the environmental control and life support functions among others.

In addressing safety in human space exploration, balancing the risk value proposition is critical. NASA's role in leading the advancement of space technology involves pushing the envelope on technology development and human exploration. In seeking the benefits of these endeavors, there are immense uncertainties and inherent risks. "Safe" as a term used in the context of large-scale, technically complex space systems and operations in the hazardous space environment, does not have the same connotation as the word in typical, day-to-day life. While there is no excuse for negligence, it is impossible to control, eliminate, or mitigate every risk. But determining the level of risk that is acceptable is far from straightforward and is not a classical scientific decision. The risk tolerance decision requires balancing many factors such as financial cost, schedule, national prestige, international relationships, human welfare, public opinion, and ethical considerations, to determine if the chance of a mishap is outweighed by the likely mission benefit.

Applying this to any plan to return astronauts to the Moon in the near term, the risk value proposition needs to carefully weigh the objectives of such a plan and its execution. Return to the Moon should not be an end in itself, but part of a larger strategy. One should ask what is the purpose of the mission? Is it structured as part of a cohesive, long-term strategy? Will the plan buy down risk for further exploration? Will the approach apply resources in such a way that there is residual infrastructure that enables next steps? Does it further a potential national goal of promoting a commercial space self-sufficiency? Does it support the nation's leadership in space and foster international cooperation? Great exploration has always included major risk – whether it was Magellan or Lewis and Clark – but it has been undertaken with an expectation of substantial benefit. Clearly articulated goals, and candid communication of the accepted risks are critical to sound leadership and decision-making.

Going hand-in-hand with the risk value proposition and a recurring theme for the Panel is Constancy of Purpose – a national steadfastness in pursuing articulated goals that does not waver over time and a willingness to support those goals with the necessary resources. Regardless of how NASA tackles the technical challenges, fluctuating policy goals, ambiguous objectives, budget inadequacies and uncertainties – including partial and full year Continuing Resolutions -- add complexity to program management and inefficiency to execution, detracting from the ability to achieve the technical goals with the requisite focus on safety and mission assurance. The consequence of not sustaining a clear and

constant purpose include program resets, associated delays in achieving goals, extended schedules, and, inevitably, increased risk.

Lastly, as NASA embarks on this next phase of deep space exploration, I encourage them in partnership with the Congress, to hold fast to the foundational standards of risk management while embracing new approaches. Hang on to the fundamentals of identifying the performance margins of their developing systems, understanding those margins and controlling operations within those margins. But do not fear alternative approaches to achieving those fundamentals.

For example, in considering the schedule for a critical flight test like EM-1, there is a critical judgment that should be made. On one hand, there is a conservative approach that argues for not flying the test until all components have been qualified, all subsystems have been completed, and there is reasonable assurance that the flight test is performed with the anticipated final configuration. This is a traditional approach, essentially performing a "dress rehearsal." An alternative could be to launch a flight test sooner in order to obtain data on integrated performance earlier in order to inform design considerations on the final configuration. Early integrated test data can advise final design decisions, but runs the risk of potentially significant differences between the test and final articles. Both approaches have merit and determining the path to employ takes a deliberate, detailed and important dialog on the risk tradeoffs for the overall program.

In that vein, NASA can learn from, and expand on, the lessons learned in the Commercial Crew Program. What developed over time in that experience – establishment of mutual trust and transparency, the employment of "badgeless teams", and the early engagement of the government – along with appropriate contract flexibility and timely decision making have the potential to not only lower costs and shorten development times, but also to reduce risk.

In closing, I will note that NASA and the nation have made significant progress in the last few years with the Exploration Systems Development Program, but much work lies ahead. This is a time for both excitement, optimism and reasoned caution.

Thank you. I look forward to your questions.

Dr. Patricia Sanders

- Chair, Aerospace Safety Advisory Panel
- Independent Aerospace Consultant
- Former Executive Director of the Missile Defense Agency (MDA)
- Former Director, Test, Systems Engineering, and Evaluation, Office of the Secretary of Defense
- Former Director of Analysis for the U.S. Space Command

Dr. Patricia Sanders is now an independent aerospace consultant after having been a Senior Executive with the Department of Defense (DOD) and retiring from the Federal Government after 34 years of service with experience in the management of complex technical programs, leadership of large and diverse organizations, and development and execution of policy at the DOD level.

Dr. Sanders retired from Government service in 2008 as the Executive Director of the Missile Defense Agency (MDA). She was the senior civilian in the Agency responsible for its management and operations, safety and quality control, strategic planning, legislative affairs, external communication, and all issues related to worldwide personnel administration and development. Previously, she had been the System Executive Officer and Deputy Director for Integration of MDA, managing program content, schedule, cost, and technical performance for the Agency's $9 billion per year program of work.

After teaching for Boise State University and the University of Utah, Dr. Sanders began her national security career with the U.S. Army in Germany in 1974. She progressed through a number of challenging positions including management of several Defense acquisition programs; positions with the Air Force Operational Test Center in space system and aircraft avionics testing; Chief Scientist for the Command, Control, and Communications Countermeasures Joint Test Force; and Director of Analysis for the U.S. Space Command.

In 1989, Dr. Sanders moved to the National Capital Area to assume the first of a number of staff positions within the Office of the Secretary of Defense, culminating with service as the Director of Test, Systems Engineering, and Evaluation. She joined the missile defense community in 1998 and participated in the establishment of the MDA, was responsible for creating its robust test organization, initiated the Sensors Directorate, and accomplished pioneering work in managing integration of the Ballistic Missile Defense System.

Dr. Sanders has actively supported professional, academic, and civic organizations, serving on numerous executive boards. She is a Fellow of the American Institute of Aeronautics and Astronautics and has received three Presidential Rank Awards for executive achievements. She was awarded the Allen R. Matthews Award for significant accomplishments in test and evaluation and the AIAA DeFlorez Award for Modeling and Simulation, which recognizes achievements in its aerospace applications.

Chairwoman HORN. Thank you, Dr. Sanders.
Dr. Lunine.

**TESTIMONY OF DR. JONATHAN LUNINE,
DIRECTOR, CORNELL CENTER FOR ASTROPHYSICS
AND PLANETARY SCIENCE;
CO-CHAIR OF THE FORMER COMMITTEE ON HUMAN
SPACEFLIGHT, NATIONAL ACADEMIES OF SCIENCES,
ENGINEERING, AND MEDICINE**

Dr. LUNINE. Chairwoman Horn, Ranking Member Babin, and Members of the Subcommittee, thank you for the opportunity to appear before you today to discuss NASA's deep space human exploration program, including proposed lunar activities.

In June 2014, the National Academies of Science, Engineering, and Medicine released a report entitled, "Pathways to Exploration: Rationales and Approaches for U.S. Program of Human Space Exploration." I co-chaired that committee together with Mitch Daniels, President of Purdue University. The Pathways report was a response to a charge from Congress in the 2010 Authorization Bill to review NASA human spaceflight and to determine the value and benefits of the program if possible.

The key findings of our report were the following: First, Mars is the horizon goal for human spaceflight for a number of reasons, but it is also decades away due to the enormous distance and the need for substantial technology development.

Second, a program to send humans to Mars ought to be based on a pathways approach, the pathways being different options by which to get there through intermediate steppingstones that provide short-term successes and technologies that can feedforward to an eventual Mars mission. The Moon represents—and particularly the surface of the Moon, represents one intermediate destination, and although it was not in our purview to choose, we found that it had the highest feedforward to humans on Mars.

Third, crucial to such a long-range endeavor are international partnerships in which the space agencies of other nations play significant and meaningful roles.

And fourth, key technologies that must be developed for humans on Mars are entry, descent, and landing on Mars; advanced in-space propulsion and power; and radiation safety, among others.

So why the Moon? The Moon offers a number of opportunities and advantages over the direct-to-Mars approach. First, the Moon is less than 5 days away, greatly simplifying logistics in response to emergency situations.

Second, the Moon provides a superb opportunity to do important planetary science, particularly regarding planet formation and evolution in the earliest history of the Earth.

Third, the Moon allows a more permanent rather than a sortie concept of operations over time as surface systems are developed, including continued development of environmental control systems that are more nearly closed and require less provisioning from Earth than does the International Space Station.

So what lessons then should the human spaceflight program and its return to the Moon take from the Pathways report? Well, first and foremost, we must be in it for the long haul. An Apollo-style

sprint to the Moon in and of itself is not a steppingstone to more distant goals in deep space exploration.

And second, the agency has to balance schedule against budget. Schedule-driven programs will cost considerably more per year than budget-driven programs, and the 2024 goal of putting humans on the Moon should not be undertaken without resources adequate to that goal but also without cannibalizing other important programs that NASA is conducting, including its remarkable space science program, which has made groundbreaking discoveries from the cosmos to the planets to the Earth.

Third, engage international and commercial partners in the program as they are crucial to a successful program of sending humans to the Moon and Mars, but the U.S. civil space program, NASA, must lead the effort.

And finally, recognize that if the Nation wishes to undertake a program of deep space exploration, it must always bear in mind and never forget that the Moon is a steppingstone. It's a steppingstone to Mars.

In remarks last month to the University Space Research Association, Scott Pace from the National Space Council talked about sustainability of exploration. One of the points he made was the programmatic sustainability in human exploration requires sustained political support, and, in turn, sustained political support requires a good cadence of successes. Taxpayers can see a return on their investment in a short enough time for the relationship between investment and payoff to be clear. And it is precisely that approach which our Pathways report endorsed and detailed in order to assure that Americans will return in a timely manner to the Moon and one day walk on the red soil of Mars.

Thank you again for the opportunity to testify today, and I look forward to your questions.

[The prepared statement of Dr. Lunine follows:]

Statement of

Professor Jonathan Lunine, Ph.D.
David C. Duncan Professor in the Physical Sciences
Director, Cornell Center for Astrophysics and Planetary Science
Cornell University

Before the

Subcommittee on Space and Aeronautics
Committee on Science, Space, and Technology
U.S. House of Representatives

May 8, 2019

Chair Horn, Ranking Member Babin and Members of the Subcommittee, thank you for the opportunity to appear before you today to discuss NASA's deep space human exploration programs, including proposed lunar activities.

In June of 2014 the National Academies of Science, Engineering and Medicine released a report entitled "*Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration*". I co-chaired the committee that produced this report, together with Mitch Daniels, President of Purdue University. The Pathways report was a response to a charge from Congress in the 2010 Authorization Bill, to review NASA Human Spaceflight with a focus on deep space civil missions, and to determine the value and benefits of the program. The key findings of the report were, in summary, the following:

(a) Mars is the horizon goal for human spaceflight, but it is also decades away due to the distance and need for technology development;

(b) A program to send humans to Mars ought to be based on "pathways" which are different options by which to get there, through intermediate stepping stones that provide short term successes, and technology that can feed forward to an eventual Mars mission. The Moon represents one intermediate destination.

(c) Crucial to such a long-range endeavor are international partnerships in which the space agencies of other nations play significant and meaningful roles.

(d) Key technologies that must be developed are (i) entry, descent, and landing (EDL); (ii) advanced in-space propulsion and power, and (iii) radiation safety, among others.

(e) Adopt a strategic approach with what we called "Pathways principles" and decision rules. The decision rules, as detailed in our report, govern how to respond to technical, cost, or schedule issues.

The Moon offers several advantages over a "direct to Mars" approach:

Proximity: The Moon is less than five days away, greatly simplifying logistics and response to emergency situations.

Science: The Moon provides a superb opportunity to exercise and extend what traditionally have been called robotic "precursor" missions – in this case, to do important lunar science, to prospect for volatiles, to map the surface, to characterize and map subterranean structures such as lava tubes – all of which will generate faster results (than what would be needed at Mars) and hopefully lead to side-by-side exploration with humans.

Testing: To establish a more "permanent" rather than "sortie" concept of operations over time as surface systems are developed – this includes continued development of environmental control systems that are more nearly "closed", requiring less provisioning from Earth than does

the ISS. On a less technical front, we have crossed vast seas throughout the history of humanity and learned to live in new lands; the Moon is our cosmic shore and we must learn to live there.

Importantly, our international partners and our commercial partners are better prepared to go forward with us to the Moon and its environs than was the case at the time the Pathways report was published. In that report we were absolutely clear that we cannot "do Mars" without those partners. The Moon represents an opportunity for us to strengthen those relationships, to extend the work done on the ISS and develop a range of technical approaches and capabilities that can only benefit us as we turn our eyes to Mars.

While the Moon is a key steppingstone to Mars, it is important not become so focused on the Moon that investments are made solely for lunar exploration, including some that might not feed forward well to humans on Mars. There are some technologies that will not transfer, but others do: for example, NASA is thinking about the lunar lander system not just in terms of how it would work on the Moon but whether it can be configured there to meet a subset of requirements that would work on both the Moon and Mars—in particular, for ascent. Learning how to mitigate dust infiltration into mechanical, electrical and biological systems is another area where, despite the differences between lunar and Martian dust, mitigation approaches for one may be applicable to the other. The radiation environment on Mars is much less severe for humans than on the Moon, but the Moon provides the hard radiation environment that will allow testing of shielding approaches for the trip to and from Mars. Finally, nuclear technologies – which our Pathways report discussed in terms of nuclear thermal propulsion, will be important on the surface of the Moon, where the lunar night is two weeks long.

What lessons, then, should the human spaceflight program take from the Pathways Report? *First*, we must be in it for the long haul. An Apollo-style sprint to the Moon in and of itself is not a stepping stone to more distant or more permanent goals in deep space exploration. Severe schedule pressures inevitably would lead to laying aside important capabilities that could benefit more ambitious, future endeavors. *Second*, balance schedule against budget. Schedule-driven programs will cost considerably more per year than budget-driven programs—the 2024 goal of putting humans on the Moon should not be undertaken without adequate resources. On the other hand, our report cautions that a budget-driven program can be stretched too thin to save money, until the interval between launches is so long that expertise...and hence safety...cannot be maintained. *Third*, we must engage international and commercial partners in the program, but the US civil space program—NASA— must lead the effort. *Finally*, recognize that IF the nation wishes to undertake a program of deep space exploration—and this must be a long-term national commitment—it must bear in mind that the ultimate payoff, and the horizon goal, is not the Moon but Mars.

In remarks to the University Space Research Association's 50th anniversary event in April of this year, Scott Pace from the National Space Council talked about sustainability of exploration. One of the points he made was that programmatic sustainability in human exploration requires sustained political support and in turn, sustained political support requires a good cadence of successes. He gave as an example scientific exploration with robotic spacecraft—the long

lineage of remarkable missions from Voyager and Viking to Cassini and Curiosity Rover, from Copernicus to Hubble Space Telescope. It is that steady cadence of successes that enthuses the public and energizes the program for more ambitious missions to come. Taxpayers can see a return on their investment in a short enough time for the relationship between investment and payoff to be clear. And it is precisely that approach which the Pathways report endorsed in order to bring humans outward from a half-century in low Earth orbit to the Moon...and then ultimately to Mars.

As I said in testimony in 2014 on the occasion of the report's release, to reach that horizon goal of Mars will require decades of sustained effort and hundreds of billions of dollars to accomplish. To be sustainable, it will require a steadfast national commitment to a consensus goal, international collaboration, and a budget that increases by more than the rate of inflation.

Our committee was not the first to say that our nation's commitment to human exploration cannot change direction election after election. But in the end our elected leaders are not the impediment to achieving great goals in space, you are the critical enablers of our nation's investment in human spaceflight. Only you can ensure that the leadership, personnel, governance, and resources are in place that will assure human beings will return to the Moon and one day walk on the red soil of Mars.

Thank you again for the opportunity to testify today and I am at your disposal for questions.

Biography: Jonathan I. Lunine is the David C. Duncan Professor in the Physical Sciences and director of the Cornell Center for Astrophysics and Planetary Science. He is interested in how planets form and evolve, how they maintain or lose their ability to host life, and whether life exists elsewhere in our solar system. Lunine is co-investigator on NASA's Juno mission orbiting Jupiter, co-investigator on an instrument for NASA's Europa Clipper mission, and is an interdisciplinary scientist on the James Webb Space Telescope. Lunine is a member of the National Academy of Sciences and has participated in or chaired a number of advisory and strategic planning committees for the Academy and for NASA, including "Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration," which he co-chaired in 2014 with Purdue President Mitch Daniels.

Chairwoman HORN. Thank you, Dr. Lunine.
Mr. Faulconer.

TESTIMONY OF MR. WALT FAULCONER,

PRESIDENT, FAULCONER CONSULTING GROUP, LLC

Mr. FAULCONER. Chairwoman Horn, Ranking Member Babin, and Members of the Subcommittee, I am honored to be here today to discuss and support NASA's deep space exploration program, first returning United States to the surface of the Moon by 2024 and onto Mars in the 2030s.

This year, while we're celebrating the 50th anniversary of the Apollo 11 Moon landing, China, India, and Israel are sending their craft to the Moon. Where is the United States?

We are currently facing a formidable challenge from China to surpass our leadership. I for one actually welcome this challenge because it helps us to focus and galvanize to maintain our leadership in space. Leveraging over 60 years that has brought us the Space Shuttle, the International Space Station, and now new craft like SLS and Orion, CST-100, New Shepard, Dream Chaser, Cygnus, Dragon, we have an armada of capabilities to build upon to return to the Moon and head onto Mars.

I applaud the goal of returning to the surface of the Moon by 2024 because it provides needed urgency and focus. It is also very achievable. It took us 7 years from President Kennedy's speech in September 1962 starting with very little to get to the Moon by July 1969 with Apollo 11. In fact, when President Kennedy gave us the challenge to go to the Moon, only three Americans had ever flown in space, Shepard, Grissom, and Glenn. That was it.

And this time it will be different. When we go back to the Moon, because besides investing in all these different spacecraft over the last 10 years, we'll be going with international partners and a very robust commercial industry.

The second core requirement is to go back to the Moon in a sustainable way. We are going back to stay. That means we have to address what are we going to do on the Moon after we get back in 2024? As I addressed in the paper I provided you, there are key questions we'll be able to answer on the Moon in our endeavor to explore, including science questions. We have discovered many new questions in science pursuits since the Apollo program that include things called lunar swirls, skylights, and the applied science providing ground truth to the resources and minerals that we have seen from orbit.

Exploration questions: Do humans have a future in space? Can we live off the land? What adjustments do our plans to Mars do we have to make along the way?

Business questions: Is there a sustainable commercial business case on or around the Moon?

National interest questions: How do we ensure American leadership in space?

The third core requirement is keeping our sights on Mars. The National Academy Pathways study that Dr. Lunine represents had a key recommendation to maintain long-term focus on Mars as the horizon goal for human space exploration. It is correct, but let's

face it, we're not ready to go to Mars today because the risk is too high.

One of the studies going on at JPL (Jet Propulsion Laboratory), for example, is quantifying the risk and determining how much of the risk can be retired by going to the surface of the Moon or identifying what risks are not being retired by anything we're currently planning. That will be important to help us create an extensible exploration architecture starting with the end goal in mind. When we go back to the Moon, we need to learn how to live off the land, live for longer durations on the surface, and deal with the hazards that the astronauts will be facing on Mars.

We can achieve all of these goals, but our largest challenge is not the technology, engineering, or ingenuity. Rather, it's overcoming the institutional momentum that slows down the process, keeps the status quo, and protects rice bowls, stifling innovation. We need to organize and streamline for success.

When Dr. George Mueller came to NASA from Bell Labs to lead us to getting to the Moon in 1963, he recognized that NASA, even in its infancy, needed to be reorganized and refocused from top to bottom. He bravely and fearlessly took on the establishment and streamlined program efficiencies borrowing from the successes of the Air Force Minuteman program while strengthening independent systems engineering by bringing on Bellcomm to provide the needed enterprise-level systems engineering and integration. All of this can be accomplished with courageous leadership.

I really look forward to very soon seeing Americans walking on the surface of the Moon and soon after walking on Mars. As President Kennedy stated, the goal will serve to organize and measure the best of our energies and skills, a challenge we are willing to accept and one we are unwilling to postpone.

Thank you very much for the invitation to appear in front of you today, and I look forward to your questions.

[The prepared statement of Mr. Faulconer follows:]

Statement of Walt Faulconer

Before the

Committee on Science, Space and Technology,

Subcommittee on Space and Aeronautics

U.S. House of Representatives

Hearing on:
Keeping Our Sights on Mars: A Review of NASA's Deep Space Exploration Programs and Lunar Proposal

May 8, 2019

Chairwoman Johnson, Ranking Member Lucas and members of the subcommittee, I am honored to be here today to discuss and support NASA's deep space exploration programs first returning the United States to the surface of the moon by 2024 and on to Mars in the 2030s. This year while we are celebrating the 50th anniversary of the Apollo 11 moon landing, China, India and Israel are sending their craft to the moon. Where is the United States? We are currently facing a formidable challenge from China to surpass our leadership in certain critical areas such as Deep Space Exploration Programs and Lunar exploration. I for one actually welcome this challenge because it helps us to focus and galvanize to maintain our leadership in space. Leveraging over 60 years of experience that brought us the Space Shuttle, the International Space Station and now new craft like SLS/Orion, CST100, New Shepherd, DreamChaser, Cygnus, and Dragon we have an armada of capabilities to build upon to return to the moon and head on to Mars.

I applaud the goal of returning to the surface of the Moon by 2024 because it provides needed urgency and focus. It is also achievable. It took us 7 years from President Kennedy's speech in September 1962 starting with very little to get to the Moon with Apollo 11 in July 1969. In fact, when President Kennedy gave us the challenge to go to the moon, only 3 Americans had flown in space, Shepard, Grissom and Glenn. That was it. In 1964, five years before the Apollo 11 mission, launch of the powerful Saturn V was still more than two years away. And this time it will be different when we go back to the moon because besides investing in these craft over the past 10 years, we will be going with our international partners and a robust commercial industry.

The second core requirement is to go back to the Moon in a sustainable way. We are going back to stay. That means we have to address what we are going to do on the Moon after we get back in 2024. As I addressed in the paper I provided you, there are key questions we will be able to answer on the Moon in our endeavor to explore including:

- Science questions – we have discovered many new questions and science pursuits since the Apollo program and that includes things called lunar swirls, "skylights" and applied science providing ground truth to the resources and minerals we have seen from orbit.
- Exploration questions – Do humans have a future in space, can we "live off the land", and what adjustments to our plan do we have to make based on what we learn along the way?
- Business questions – Is there a sustainable commercial business on or around the moon?
- National Interest questions – How do we ensure American leadership in space?

The third core requirement is keeping our sights on Mars. We need an approach that is extensible to getting us to Mars. The National Academy Pathways study that Dr. Luine represents had a key recommendation to maintain long-term focus on Mars as the horizon goal for Human space exploration. It is correct, but let's face it, we're not ready to go to Mars today because the risk is too high. One of the studies going on at JPL for example is looking at quantifying the risk and determining how much of the risk can be retired by going to the surface of the Moon, or identifying what risks are not being retired by anything we're planning. That will be important to help create an extensible exploration architecture, starting with the end goal in mind. When we go back to the Moon we need to learn how to live off of the land, live for longer durations and deal with the hazards that astronauts will face on Mars. All of this will be essential to understand before we send humans on that very long journey to Mars.

We can achieve these goals but our largest challenge is not the technology, engineering or ingenuity rather it is overcoming the institutional momentum that slows the process down, keeps the status quo, and protects rice bowls or "programs of record". We need to organize and streamline for success. When Dr. George Mueller came to NASA from Bell Labs to lead us getting to the Moon in 1963 he recognized that NASA even in its infancy needed to be re-organized and refocused from top to bottom. He bravely and fearlessly took on the establishment and streamlined program efficiencies borrowing from the success of the Air Force minuteman program while strengthening independent system engineering with bringing on Bellcom to provide the needed enterprise level systems engineering and integration. All of this can be accomplished with courageous leadership - leadership of this committee and people at this

table. I look forward to very soon seeing American's walking again on the surface of the moon and soon after walking on Mars.

As President Kennedy Stated, "The goal will serve to organize and measure the best of our energies and skills. A challenge we are willing to accept and one we are unwilling to postpone" Thank you very much for opportunity to appear before this committee and I look forward to your questions.

"Boots on the Moon"
The Next Step to Enabling Human Expansion Across the Solar System
A purpose-focused integrated space exploration campaign to return to the Moon

1.0 INTRODUCTION

President Trump signed Space Policy Directive-1 on December 11, 2017. It stated that the United States is 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. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations.*

The direction is clear to set a logical and unambiguous path forward with realistic near-term goals. ***The next step is to execute, to accomplish this direction with urgency and purpose.***

To expand human presence across the solar system we need to first explore and exploit the potential of the Moon. Much more is known today about the potential benefits of the Moon than was known in the days of Apollo. We have learned from the Apollo experience and lunar samples with continuously advancing technology and observation. The Apollo samples provide evidence of oxygen content in the regolith on a global scale. We now have discoveries from lunar satellites and probes that have globally characterized surface features, mapped resources, and determined the Moon's planetary characteristics. The Lunar Reconnaissance Orbiter (LRO) and the Lunar Crater Observation Sensing Satellite (LCROSS) have proven the existence of water (ice) in permanently dark craters at the poles. This has led to new and compelling ideas on what could be accomplished in sending robots and explorers to the lunar surface.

This detailed knowledge has led scientists to identify multiple locations on the Moon with high potential for further discoveries. For example, we have recently discovered the existence of over 300 "skylights" or possible lave tube entry areas leading to potentially massive underground caverns. It has provided the maps and information needed to seek ground truth on the lunar surface. Exploration for in-situ prospecting can determine in what form the useful resources exist and the appropriate techniques for extraction and production.

Fifty years after the Apollo Moon landings, it is time for the United States to return to the Moon with the purpose of exploration, science, national interests, economic development and leading the way to Mars. Building on the national investments and capabilities that NASA has been developing including the International Space Station (ISS), the Space Launch System and the Orion Crew Exploration Vehicle we are ready and better positioned for the next chapter of exploration leveraging 1) private investment and commercial development that is currently providing essential transportation and satellite services, and 2) an international community brought together through the ISS that now has significant capabilities to offer. Not unlike the Mercury-Gemini-Apollo campaign, our new missions can increase in complexity in support of these goals, building on and adapting to the discoveries along the way. ***It is time for 'Boots on the Moon' again!***

2.0 OBJECTIVES AND GOALS

The Exploration Campaign has five strategic goals:[1]

1. Transition U.S. human spaceflight activities in low-Earth orbit to commercial operations that support NASA and the needs of an emerging private sector market.
2. Lead the emplacement of capabilities that support lunar surface operations and facilitate missions beyond cislunar space.
3. Foster scientific discovery and characterization of lunar resources through a series of robotic missions.
4. Return U.S. astronauts to the surface of the Moon for a sustained campaign of exploration and use.
5. Demonstrate the capabilities required for human missions to Mars and other destinations.

What is missing is a clear integrated outcome-driven campaign plan that connects these together into a portfolio as to how, when, why, what, who, and where. The United States must lead and integrate the top-level vision with the various elements that NASA, industry and international partners are developing. We need to answer basic questions of what we are going to do on the surface of the Moon, do humans have a future in space, can we "live off the land", and how does lunar exploration prepare us for Mars exploration, as shown in Table 1. This integrated definition is needed to enable NASA leadership to coordinate across the stakeholder community to re-focus government, industry and international participants into an executable campaign with purpose and urgency.

Table 1 The campaign portfolio approach supports each stakeholder in answering key questions, and achieving their goals with compatible strategies.

	SCIENCE	EXPLORATION	BUSINESS	NATIONAL INTERESTS
DRIVING QUESTIONS	Is there life elsewhere? How did we get here? Where are we going?	Do humans have a future in space? Can we live off the land? What are we going to do on the Moon?	Is there sustainable commercial business in lunar space beyond the Government?	How do we ensure American leadership and values in space?
GOALS	Answer fundamental origin questions	Explore for national interest	Develop long term markets and competitive advantage	Strengthen our relationships with our friends and protect from our enemies
STRATEGY	Follow the water	-Explore in a sustainable way -Boots on the Moon -Prepare for Mars -Create economic & international benefit along the way	-Public-private partnerships -Private investment	-U.S. leadership -Secure the high ground

[1] NASA Space Exploration Campaign Report, September, 2018, pg. 5.

3.0 LUNAR DEVELOPMENT

The development of the Moon follows an "early enabler" or catalyst model followed by methodical, evolutionary, adaptive and integrated processes. Recent studies show that there are high concentrations of oxygen in the lunar regolith. Supplies of oxygen are essential for human life support (air and water), rocket propellant, and other needs. Oxygen availability as a resource provides a basis for development of commercial markets and services. Therefore, one likely early enabler is the oxygen economy. However, the lunar exploration campaign is flexible to evolve based on what we discover and learn along the way

The O_2 Economy as a Possible Foundation

There have been many ideas suggested as to how the Moon can be used. A recent study by Roscosmos and the European Space Agency shows promise of utilizing lunar soil for 3D or alternative manufacturing of lunar habitats and space hardware.[2] Mining of volatiles or water has long been cited as a possible resource.

Oxygen is the most abundant element in the lunar soils, constituting 40 percent of those soils by weight.[3] Oxygen makes up approximately 85% of the weight of a typical spacecraft at launch, as oxidizer for the rocket fuel. Oxygen mined from the Moon can play a pivotal role for developing a new space economy needed for exploration, lunar development and even refueling of Earth orbiting systems. Besides giving the United States leverage in our space transportation leadership, lunar oxygen can become one of the lunar economy's first and most important economic export.

Moon dust or regolith is a mixture of many different minerals, and nearly all of them contain oxygen in considerable abundance. One of the most common lunar minerals is *ilmenite*, a mixture of iron, titanium, and oxygen. (Ilmenite also often contains other metals such as magnesium). The processes to extract oxygen are very straightforward. Processes so far studied for extraction of oxygen from lunar soils are fluorine wet chemistry, the reduction by hydrogen of ilmenite (iron-titanium oxide), and electrolysis. The reduction processes, particularly those which use hydrogen as the reducing agent, are the most technologically mature. Oxygen which is chemically bound to iron in lunar minerals and glasses can be extracted by heating the material to temperatures above 900°C and exposing it to hydrogen gas.[4] The University of Cambridge has demonstrated extracting O_2 from lunar rocks through an electrochemical process. MIT is working on a high-temperature technique called molten salt electrolysis that can extract O_2 from the Moon's regolith. Production of LLOX (lunar liquid oxygen) from ilmenite (FeTiO3) in fluidized-bed reactors can be the pathfinder for an expanding economy including use of regolith to shield an expandable habitat complex, paving to control dust production, and power management tuned to the mid-latitudes' 2-week lunar night.[5]

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[2] Dmitry Rogozin, Chief, Russian space agency Roscosmos, Nov 3, 2018. *Europe's Vision of a Future Moon Base*, Made out of Moon Dust, Universe Today, Nov 23, 2018.

[3] Pioneering the Space Frontier, The Report of the National Commission on Space, Aug 14, 2009.

[4] Oxygen Extraction from Lunar Samples, *by Carlton C. Allen, Lockheed Martin Engineering and Sciences Co., NASA JSC, 2006*

[5] *Principles of a Practical Moon Base*, Brent Sherwood, IAC-18.A3.1.6.X46496, Oct 2018, Pg. 1.

Another consideration is that the regolith needed is everywhere on the Moon. Lewis and Clarke blazed a trail that appeared to be the path of least resistance to get across the Rocky Mountains. Likewise, it makes sense to follow the lunar path that appears to have high benefit and low risk. More difficult and challenging locations like cold traps at the poles likely containing frozen water are very challenging to reach and extract with near absolute zero environments. Eventually our abilities can expand to include volatiles like water which is important for future development, but the oxygen economy is the right first step given its access, low risk process and significant economic leverage. This first step can demonstrate our ability to "live off the land" versus always bringing everything needed from Earth, as illustrated in Figure 1.

Additionally, the process of extracting oxygen from Ilmenite creates a spinoff of Titanium. Today on Earth, most titanium metal is produced from rutile laboriously mined from sands in Florida and Australia. However, if in an evolutionary, efficient process for Titanium is developed for extracting rutile from ilmenite, we might serendipitously have an economic effect on the world's titanium production as well as resources for in-situ fabrication of surface assets.

Lunar oxygen provides great benefits in production of breathing air and oxidizer for rocket fuel. It is very likely that water ice can also be recovered from craters, providing drinking water and effective radiation protection for crews. Hydrogen for rocket fuel is the most efficient of all chemical propulsion. Hydrogen and oxygen can be used together in fuel cells to produce power. The pursuit, development and exploitation of oxygen and hydrogen guides exploration activities and operations. The highest priority is to establish the knowledge of where and how best to extract oxygen from indigenous regolith. The process of establishing the oxygen economy results in missions and infrastructure, in a deliberate and focused fashion that enables other established objectives. Exploration and science discoveries can be achieved.

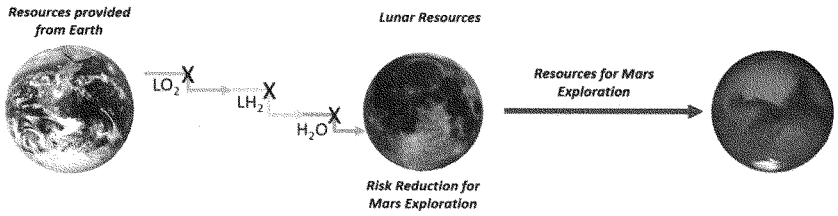

Figure 1 The government enables industrial development of lunar resources, breaking the dependence on Earth and feed-forward to Mars exploration. Creating an O_2 economy is a logical first step of utilizing lunar resources thus reducing the amount of resources brought from Earth.

This campaign has many important possible outcomes including identification of other resources that may have production value. It enables testing and maturation of technologies and

operations that accelerate the knowledge needed for human Mars missions. It further enables collaboration and friendships with our international partners in space, and opens possibilities for commercial activity through the buying and selling of commodities and services. The endeavor motivates educational initiatives with new knowledge of the Earth's neighborhood, our solar system and universe. The successful development of an oxygen economy provides the impetus to grow a lunar base or even bases, depending on an understanding of the return that can be realized. U. S. leadership of these achievements establishes the United States as the leader in setting the "rules of the road" in the lunar vicinity, establishes the precedents for continued exploration and utilization, enhances our national pride and the desire for further exploration of space, not to mention our security.

Because of our current understanding that oxygen is global, and yet concentrated in permanently dark craters, the first landing site of explorers could be at the Moon's North or South Pole near a promising permanently dark crater, where prospecting and experiments can determine extraction techniques for oxygen in both forms. The choice of exact location also considers high priority science objectives. An advantage of a polar location is also the availability of longer-term solar power and thermal stability than is available away from the poles. Detailed objectives and decisions shall be determined with broad community input, including civilian and non-civilian government agencies, the science community, international space agencies, industry, academia, space policy experts, Administration and Congressional stakeholders, etc.

Build out Lunar Development

Lunar development based on prior systematic step-by-step initiatives can occur. Further, new initiatives can be expected based upon exploration and science discoveries. Business partners are likely the primary initiators within the build-out lunar development phase. This phase should include government investment and incentives in support of infrastructure such as transportation, power, communications and navigation aids.

Portfolio Lunar Development

The lunar development entities, all with different agendas, need to be coordinated as a portfolio throughout the various phases of development. (e.g. initial, build-out, adaptive). As we learn from exploration, economic development, science, international and national interest the portfolio is rebalanced along the way. Coordination of different agendas requires compromise but not cancellation of entities goals and objectives. This portfolio coordination ensures cost-effective resource handling, efficient interfaces, minimize overhead costs, and enhance mission achievement. It also enables on-ramps and off-ramps as we learn and answer key questions along the way.

Adaptive Lunar Development

All lunar development participants, perhaps from the start, are faced with the quintessential challenge - 'We don't know what we don't know'. This fact of lunar exploration requires adding risk mitigation backups as a part of resource and cost development planning as well as flexibility in the planning to address new discoveries. As difficult as defining and planning for the impact of the unknown is, it is a greater impact not to include some best estimate by all participant planners.

4.0 Lunar Development Endeavors

Development endeavors evolve differently between exploration, science, commercial business, and national security. Each endeavor has different thrusts in demonstrating essential capabilities as illustrated in Table 2.

Exploration

The U. S. government's unique role in space is to lead in answering questions through exploration, where there is an uncertain but potential return for national, public and commercial interests. With the policy set in Directive 1, NASA is positioned to provide the leadership and initial investment to set this policy in motion to benefit all interested parties fairly. The exploration aspect of the endeavor supports national interests, business, science, and international relations in space by providing leadership, the operations and means to accomplish their objectives. Exploration drives technology and provides testing opportunities, operational capabilities, and uncovers knowledge from discoveries. As a unique exploration objective, experimentation and achievements at the Moon enables further understanding of what it takes for the next steps in exploring Mars.

While NASA's leadership and initial investment is key to helping create the lunar economy, it is important to reflect upon how far human spaceflight has advanced over the last 60 years and the role of NASA for the next phase. We are on the cusp of private industry sending humans into low Earth orbit, and advances in commercially available launch services open a range of new possibilities for government and industry to both pursue their own outcomes on the new frontier. NASA can play a first-among-equals role in this respect, clearly pursuing its exploration and discovery agenda toward a future human mission to Mars, as well as establish a regulatory and infrastructure environment in the lunar vicinity that private industry can leverage for its own purposes, be they purely commercial or as services to the government (further described in the next section).

Astronauts supporting scientists on Earth collect lunar samples to compare details of the actual oxygen and other resource concentrations and composition with remote measurements from lunar orbit. The form of these resources is also investigated to understand how they are combined mechanically or in compounds within the rocks and regolith. This informs designs of machines to recover and extract the desired elements. Astronauts perform experiments with

techniques to extract oxygen, water ice and other desirable minerals to inform science and industry as they plan the mining operations that look most promising.

Table 2 Lunar endeavors for Exploration, Science, Commercial Business and National Security

"Boots on the Moon" What are we going to accomplish?	**EXPLORATION**
	-Explore new parts of the Moon and provide essential "ground truth" through prospecting promising locations -Demonstrate surface mobility and resource utilization: In-Situ Resource Utilization (ISRU) -Identify and mitigate risks for Mars exploration -Pave the way for commercial development (leave behind initial capabilities & infrastructure), e.g. reusable lander
	SCIENCE[6]
	-Establish the period of giant planet migration and its effects in our solar system (The Moon contains the solar systems and bombardment record) -Provide an absolute chronology for Solar System events -Use the accessible vantage from the lunar far side to view deep space and the Universe -Understand and utilize the special water cycle of the Moon and other airless bodies (The Moon has all 3 forms of water: endogenic, sequestered external and in-situ) -Characterize the Moon's interior to reveal how this differentiated neighbor of Earth formed and evolved (Lunar Geophysical Network) -Evaluate the extended record of space weather and fundamental processes of plasma interactions with surfaces. -Lunar swirl investigation. -Lava tube/skylight investigation
	COMMERCIAL / INDUSTRIAL ECONOMIC DEVELOPMENT
	-Leverage cost-effective Government incentives with private investments - ISRU/production of LO2, H2O, H3, LH2, titanium, etc. -LH2 delivery from Earth and other resupply services -Small / Medium Commercial Landers for Science and Technology -Large commercial vehicles (e.g. landers, and surface transportation) for humans, resources, development and services - Exploration infrastructure, e.g. communications and navigation Construction and services dedicated to Mining initialization and expansion. - Lunar-oriented satellite placement, operations, and associated services. - Arena for Multinational cooperation opportunities in commercial endeavors.
	NATIONAL SECURITY
	-Leadership and establishing the "rules of the road" -International participation and partnership -Cis-Lunar Access and Situational Awareness -Build the industrial base & infrastructure with friends and allies enhancing foreign policy

The U. S. led international teams of explorers witness much more extreme and dramatic vistas than even those of the Apollo era. During Apollo, benign landing sites were chosen in those first steps, because so much was unknown. Their experiences of these modern explorers are shared with the people on Earth as all are inspired with the new lunar home. The experience and discoveries motivate education and the aspirations of our youth.

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[6] Transformative Lunar Science, Dr. Carle Pieters, Dr. Robin Canup, Dr. David King, Dr. James Head, Astronaut David Scott, January 2018.
NOTE: This is a summary. There are many other science objectives documented by the Lunar Exploration Analysis Group (LEAG)

Astronauts learn the techniques of working with hardware on the lunar surface. They will gain experience in new space suit designs in the reduced gravity. Their health will be monitored to study the physical effects of living in gravity, thermal, lighting, dust, radiation and other environments that are much different than what people encounter on Earth. Designs will be tested and evolved to mitigate the deleterious environmental effects. Astronauts will test operational techniques including scientific tasks such as digging, sampling, and observation that will not only improve lunar operations, but will feed forward to future Mars missions. Designs for landers, rover transportation, life support, habitation, power, and other hardware used in these operations will also be chosen to test details that will feed forward to Mars designs.
The exploration role of lunar astronauts will pave the way for those who choose to follow and take advantage of the knowledge gained, while NASA pursues new objectives at the Moon and/or plans for the next destination- Mars. After the lunar experience, we will have a much better-informed understanding of those challenges.

Business Economic Development

Business enterprise participation is motivated by profit and developing long term competitive advantages. Government entities are motivated by national objectives and goals. History, has shown the two arenas do not always conflict and mutually support each other (e.g. U.S. 19th century frontier expansion, and 20th century national highway system). This historical intersection is the *key theme* concerning Lunar Evolutionary Development (LED). The following economies are a listing of potential Business and Industrial opportunities at the start of LED. LED economies are characterized as having NASA initiatives developing an 'Anchor Tenant' (providing basic exploration, infrastructure, and services). Subsequent expansion within the LED opportunities is solely within the Business and Industrial domain driving towards maximum commercial opportunity investment and revenue success.

The Transportation Economy - Transportation demands providing surface mobility is needed with the first arrival of 'Boots on the Moon' activities. Initial (1-2 years) exploration requires multi-functional lunar surface transport (MLST) vehicles to meet exploration and science requirements providing access to lunar regions of interest for mapping, geological testing, establishing ground truth along with providing logistical services for initial site establishment. Both the transportation of personnel and materials is required accommodating multi-passengers, increasing cargo mass with a longer surface range of designations. Long-term surface transportation is determined by the rate of growth of exploration, science and economic development on the lunar surface. The transportation economy business and industrial economy provides multi-layered opportunities to meet requirements including increasing transportation fleet capabilities, maintenance, energy services, storage, supplies, spare parts, mission customization, shuttle service, along with towing and recovery. NASA may require the initial fleet (2-3 vehicles) be government procured to support exploration and science needs. However, surface transportation services are a likely commercial endeavor for business and industrial expansion.

The Mining Economy - Compared to the Apollo era, LED mining leads the enterprise from the start; a) Building upon prior exploration from the science community, alongside industry, defines their mission objectives and goals to extract life-supporting elements for lunar residing and operations (e.g.

Explorers/miners at the Moon's Poles where oxygen concentrations are in permanently dark craters, longer term solar power, and thermal stability); b) Business/industrial mining efforts will expand at a greater pace upon earth-adaptive operations brought to the Moon in search/development of heavy metals, further basic resources, rare earth elements; energy requirements, etc. (e.g. lunar regolith [3-20 meters], bedrock/crust of the Moon [> 60 kilometers]); c) Long-term mining is notional but can be expected to support an ever increasing/evolving lunar infrastructure as resources extracted are utilized for lunar manufacturing operations, earth-export products, orbital services, Mars exploration initiation.

The Services Economy - People require a diversity of support services as they begin to occupy the Moon on a more permanent basis, whether for research, exploration, resource extraction, solar system observation, or as a departure point for trans-lunar and deep space missions. Material, tools and equipment are needed to be stored, serviced and repaired. Infrastructure is developed including garages for lunar transporters, satellite servicing, robotic maintenance, and long-term research laboratories. Servicing and repair of space suits is one of the first required services given the lunar dust environment. Medical acquisition both on site and remote response service is required as the number and frequency of lunar activity increases. These key demands exceed the basic services of the 'Anchor Tenant' capability and open significant commercial opportunity.

Further, human needs are to be accommodated, initially with bare necessities but over time and with an increasing cadre, the standards of service need to mimic those available on earth. Training, hotel services, food, laundry, telecommunications, and entertainment are examples of these expanding services. Moon-based agriculture provides fresh food to the increasing lunar population reducing dependence on Earth resupply. Moon residents need contact with Earth-bound family and friends through high definition communications.

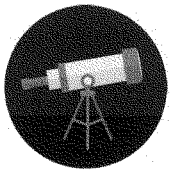
The service economy provides unique opportunities for earth-based private sector companies to expand their expertise into the space domain.

Private Investment Coupled with Government Incentives: History is replete with examples of government-established functions that have been transitioned to the private sector, fully or partially including Intelsat, Inmarsat, the Tennessee Valley Authority, the Federal National Mortgage Association (FNMA), to name but a few. The transition for many of these organizations took a long period of time, and often a number of rearward steps. Bringing commercial companies in at the beginning is key to enhance success versus the usual "build it and they will come" approach often used. These companies have the experienced insight to envision more cost-effective approaches that are more likely profitable.

One of the government's objectives in the establishment of a lunar base of operation is to attract private sector investment in and operation of Moon-based industrial and commercial enterprises from the outset, including non-traditional aerospace. The government needs to create mechanisms to address commercial market financial and technical risks. Most public companies are risk averse. For example, today there are numbers of companies growing crops in vertical

"urban farms." Some crops are grown hydroponically while other crops are seeded and grown in trays that rotate for sunlight exposure, drip and spray watered, excess water cleaned and recycled. A first "Moon farm" would combine government experience and assurances with lunar operations with urban farm technology in a small-scale "package" farm transferred to the Moon. The government would have to pay for this demonstration farm and provide an initial guaranteed market for the crops. As other entities inhabit the Moon, private investment would scale the farm. At this point the Moon farm would reflect the institutional, market, financial, and technical risks of operating on the lunar surface. It is likely that the government would continue to provide Earth-lunar transport for companies by paying for transport on commercial rockets. Over a longer time, horizon, even these costs would migrate to the companies as they gain operational experience.

To start developing the markets and the requisite business plans, government entities need to help address the key technical and market risk areas to build the capability. In addition, government entities also need to serve as "anchor tenants" to purchase services to "seed" the marketplace. As an "anchor tenant" the government would evaluate competing commercial initiatives to ensure sound investment of taxpayer funds. Government funding models have to extend beyond the typical contractor relationships and into industry and marketplace development partners. Approaches from the development leading to commercial air travel would be useful analogs to pursue for lunar business models.



Science

Beyond building a Lunar Economy, there is plenty to learn about the Moon. Science plays a critical role for NASA and USG involvement on the Moon and the broader exploration objectives.[7] A half-dozen scientific missions have revealed a Moon Apollo never knew. Today we know the Moon holds a large inventory of polar volatiles, in various forms: adsorbed solar wind, accumulated crystalline water ice and even surface frost in some PSRs (permanently shadowed regions), and perhaps deep ice from ancient cometary impacts. The science community has also developed a prioritized list of about two dozen key investigation sites around the lunar globe.

Among other objectives, absolute chronologies can calibrate ages across the solar system. The Moon preserves many of the geologic processes that occurred early in our Solar System and during the period when life formed. It preserves a record of the impact history over geologic time. Such records have been obliterated on planetary bodies that are active and have atmospheres. The Moon also preserves a record of the Sun's activity in its regolith and the early evolution of terrestrial planets. Volatile deposits at the lunar poles may contain a record of the volatiles transported to the inner Solar System. The radio-quiet lunar far side enables

[7] The Global Exploration Roadmap, ISECG, Jan 2018

astrophysical investigations into the earliest stages of our universe through the deployment of radio telescopes. Human presence on the Moon would permit detailed geologic mapping, the collection of critical samples for analysis in Earth-based laboratories, and the emplacement of delicate instrumentation, including seismometers and other geophysical instrumentation.
Specific examples of high value lunar science are described back in Table 2[8] and the NASA Lunar Exploration Analysis Group (LEAG) has recently published the key science concepts for future investigations shown in Table 3. As with all science, we don't know what we don't know and as we answer the key questions that currently exist along the way, a magnitude of new questions arises. Therefore, we now have better prospects for using the Moon to bootstrap off-world achievements. Scientifically, the stage is set for a robust lunar program.

Table 3 The LEAG Themes Driving Lunar Science Investigations

Concept 1: The bombardment history of the inner Solar System is uniquely revealed on the Moon.
Concept 2: The structure and composition of the lunar interior provide fundamental information on the evolution of a differentiated planetary body.
Concept 3: Key planetary processes are manifested in the diversity of lunar crustal rocks.
Concept 4: The lunar poles are special environments that may bear witness to the volatile flux over the latter part of Solar System history.
Concept 5: Lunar volcanism provides a window into the thermal and compositional evolution of the Moon.
Concept 6: The Moon is an accessible laboratory for studying the impact process on planetary scales.
Concept 7: The Moon is a natural laboratory for regolith processes and weathering on anhydrous airless bodies.
Concept 8: Processes involved with the atmosphere and dust environment of the Moon are accessible for scientific study while the environment remains in a pristine state.
New Concepts that must be considered as we move into a new phase of lunar exploration.

- *The Lunar Volatile Cycle*
- *The Origin of the Moon*
- *Lunar Tectonism and Seismicity*

National Security Interests

It is in the U. S. interest to lead the world in exploration of the Moon. After many years of collaboration with international space agencies, NASA is looked to as the leader in space exploration. It has been and continues to be clear that all the other international agencies have a preference for the Moon as the next destination to explore. As espoused by Alfred Thayer Mahan in "The influence of Sea Power on History, 1660 to 1783," nations who control the sea, control their destiny. It is a perfect analogy to our era in space. To continue our leadership as a fair international partner helps to ensure that

[8] Transformative Lunar Science, Dr. Carle Pieters, Dr. Robin Canup, Dr. David King, Dr. James Head, Astronaut David Scott, January 2018.

the playing field is controlled with integrity. It is imperative that we maintain that role. The exploration of the Moon drives U. S. technology and the U. S. space industrial base. It also is important for the U. S. to lead in lunar commerce that is generated. The Moon provides a stable and solid satellite for observation and communications for the Earth-Moon system including cis-lunar space. It is important to secure this capability.

5.0 Legal Considerations

The potential development and usage of lunar resources has been a topic of legal resolutions since the late 1960s. The United Nations (U.N.) has been in the forefront of passing several Treaties (agreed by all Nations) regarding lunar Sovereignty and Property Rights (e.g. early 1960s General Assembly declarations; 1967 Outer Space Treaty; 1979 Moon Agreement). Principally, the 1979 Moon Agreement, the current presiding document, has far-reaching lunar development requirements and restrictions. The United States is not a signatory to the 1979 Moon Agreement and not bound by its provisions. However, the U.S. Congressional Commercial Space Launch Competitiveness Act of 2015 is the single current U.S.-centric legal/policy document influencing both Governmental and Industrial entities and initiatives.

"But above all else, we choose to lead in space because we know that the rules and values of space, like every great frontier, will be written by those who get there first – and we owe it to mankind to bring American values to the boundless expanse of the heavens." (Vice President Mike Pence, first meeting of the National Space Council)

The development of space will depend on the development of laws, regulations, and institutions that support and enable the expansion of human activity into this new domain.[9]

6.0 Summary

Our Administration has wisely recognized that our nearest neighbor, the Moon, holds an abundance of opportunities for commerce, international collaboration, science and further exploration. Clearly, the United States as the most accomplished leader in space must continue in that auspicious role. The Moon holds great potential for our future and must not be overlooked on our way to Mars. Successfully developing an ability to leverage lunar resources may have a fundamental impact on how and when a human Mars landing might be achieved. Mastering the Moon and its environment prepares humanity for interplanetary flight. We are overdue in returning explorers to the lunar surface.
In the mean time we have learned a great deal from experiences in space with advanced vehicles, amazing missions, international space relations, and both past and current lunar investigations. This knowledge inspires the direction for our return. Current commercial endeavors, experience on the International Space Station, and building of the Space Launch System and Orion have provided the basis for our successful return. Striving to build an economy at the Moon focuses

[9] *Space Development, Law and Values*, Dr. Scott Pace, IISL Galloway Space Law Symposium, December 12, 2017.

our campaign for a self-sustaining path for the future and enables our numerous lunar and space endeavors. We must seize lunar opportunity, enabling the foundation for solar system exploration opportunities, and provide a stable path forward that can be supported by our broad space community as it answers their objectives. With the right direction we can accomplish the "boots on the Moon" vision propelling exploration, science and economic development motivating positive aspirations for a new generation and provide positive outcomes that benefit all the people of Planet Earth.

"Boots on the Moon" The Next Step to Enabling Human Expansion Across the Solar System
RECOMMENDATIONS

Visibility, consensus building, participation, and buy-in for sustainable success

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1. **FINDING:** NASA Science Mission Directorate (SMD) and the science community does an excellent job of establishing goals, objectives and programs that garner wide community support. The established process of National Academy Decadal Survey, conducted by the National Science Foundation, funded NASA studies on the feasibility of key missions and broad consensus building and advocacy through the various Analysis Groups (Lunar Exploration Analysis Group-LEAG, Mars Exploration Program Analysis Group-MEPAG, Outer Planets Analysis Group-OPAG, Small Bodies Analysis Group-SBAG and Venus Exploration Analysis Group (VEXAG). The only parallel on the human exploration initiative is the International Space Exploration Coordination Group (ISECG). The human exploration program is driven more by NASA internal aspirations along with a few states and contractors that directly benefit.

RECOMMENDATION: We recommend that for the success of sustained human exploration there needs to be a similar domestic US structure that provides transparency, broad input and consensus building in the various human exploration, science, commercial development, national security and international communities. Similar to the science decadal process, this structure should exist outside of NASA where the agency is an active participant and principle respondent. Consider the formation of a National Space Council Implementation Working Group that could serve as a Human Exploration Program Analysis Group (HEPAG) coordinating with these communities along with the LEAG, MEPAG, and ISECG. We also recommend that each of these analysis groups need to be evaluated for maximum possible representation for buy-in, input, and advocacy.

2. FINDING: New exploration initiatives have a better probability of success if community involvement is sought and incorporated providing stakeholder buy-in. For example, after the

Vision for Space Exploration was revealed several events helped to communicate and enable stakeholder involvement. These include the AIAA Space Exploration Conferences, the first being held in Jan 2005 and the Lunar Development Workshops held in 2006 bringing together all stakeholders in an actual "working" workshop to develop further details in the exploration objectives and roadmap. Following the cancellation of Constellation, several initiatives were announced by NASA including Humans to Asteroids and the Asteroid Redirect Mission which did not utilize broad stakeholder involvement and participation and thus garnered significant criticism. Having a few people make decisions to "send humans to an asteroid" or "build a Gateway" without broad stakeholder participation significantly reduces the sustainability of such long term programs.

RECOMMENDATION: We recommend that similar Exploration Conferences and Workshops be planned in early 2019 and executed in conjunction with NASA, the stakeholders and aerospace professional organizations including AIAA and AAS. The cost of these efforts is minimal considering the advocacy, participation, education and public outreach, "excitement", and buy-in that they can garner.

3. FINDING: The NASA-produced National Space Campaign Report, published September 2018 attempts to address many of the issues identified in this white paper but falls short in many areas including the lack of stakeholder participation and lack of answers to fundamental questions such as "what are we going to do on the moon" and "why is a gateway required? The current document comes across as a plan to build ISS-2 at the moon versus a real campaign plan focused on lunar exploration and development.

RECOMMENDATION: We recommend that we continue the work started with this White Paper under the direction of the National Space Council and NASA to perform a "virtual think tank" approach to build a better, more inclusive campaign plan that can be used as the departure document for a Stakeholder Workshop and Conference in 2019. This effort would eventually be part of the HEPAG to sponsor and facilitate.

Organize for long-term success

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4. FINDING: NASA's organization especially HEOMD is currently better organized for operations, coming out of operating the Space Shuttle, the ISS, launch services and infrastructure (i.e. TDRSS). New development for space is hard. The current organization has had significant issues in effectively managing new development as indicated in recent GAO and IG independent performance audits. This is mainly due to the necessary difference in mindset between operations which is capability and service driven, and development which is outcome driven. Efficient operation is different from effective new development and the lines are currently blurred.

RECOMMENDATION: Separate HEOMD into two separate Directorates. The Development Organization needs to be outcome or mission focused with roles, responsibilities and accountability along with experienced leadership and expertise for the development life cycle. The second organization should be focused on providing efficient and cost effective operations and services. Overall organization from HQ to Centers needs to be evaluated and aligned for success of programs and missions as opposed to institutional desires. There also needs to be clear criteria and processes for transition from development to production and operations. The development organization should have clear "outcomes" driven by operability and life cycle cost. The operations organization should maintain representation in the development effort to ensure new development is aligned with cost-effective operations.

Systems Engineering and Integration

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5. FINDING: There is a lack of independent Plans, Analysis and Evaluation (PA&E) function to provide the data, system trade-offs and evaluations to 1) ensure effective decision making by the Administrator's office, and 2) provide independent quality control of important program, management and budget decisions, and 3) provide an integration function across the mission directorates and other NASA functional areas.

RECOMMENDATION: Re-establish an independent PA&E organization that reports to the Administrator. This organization needs the skills and resources including access to independent subject matter experts and FFRDC resources.

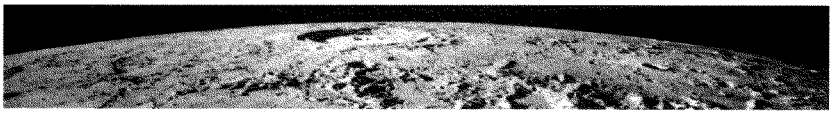
6. FINDING: NASA has a lack of robust systems engineering and integration for the large-scale development due primarily to the infrequency of such developments, which prevents sustainment of a strong pipeline of systems engineering talent. Such talent is required for formation and execution of an integrated campaign including SLS, Orion, a Gateway, lunar landers, surface development, Mars preparation, etc. This is evident by continued system disconnects between SLS, Orion and Ground Systems working to sub-optimal requirements with a relatively poor understanding of key driving requirements and outcomes (e.g. what is to be accomplished on and around the moon?). Recent GAO and IG reports highlight the weakness.

RECOMMENDATION: NASA needs to reinvigorate and supplement its SE&I capabilities for effectively managing the Exploration campaign, especially at the "system of systems" level. Given the overall erosion of internal SE&I capabilities utilizing an independent, with hardware exclusion SE&I contractor, FFRDC or team should be investigated where NASA leverages government trusted agent capabilities with high acumen in systems engineering. There also needs to be clear leadership at the Program Director level at NASA Headquarters integrated with clear lines of responsibility and authority across the SE&I resources actually performing the work at the Centers. The NASA Programs and Centers must be held accountable for the overall leadership, with clearly defined programmatic and technical decision authority directly traceable and responsive to a clear set of outcome-focused requirements. This approach also needs clear

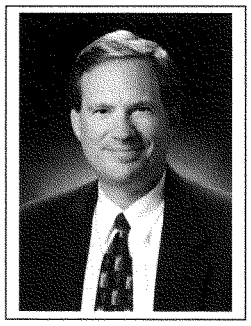
measures of effectiveness along with the longer-term plan to re-build a strong SE&I capability back within the agency.

7. FINDING: NASA, over the past decade, has responded to lack of budget support for exploration by making difficult but pragmatic decisions relative to exploration systems development. This has resulted in a "capability driven" management model that treats schedule as a "free variable" and lacks definition that is driven by clear needs, goals and objectives related to specific destination outcomes. Therefore, we observe the difficulty NASA is having cultivating stakeholder support for the Gateway concept.

RECOMMENDATION: Use the IWG/HEPAG to establish clear "Level 0" needs, goals and objectives – informed by both public and private sector outcomes - to which NASA's development organization can then respond with a clear set of systems engineering requirements and a fully responsive architecture. Lacking this, with obscure and litigious rationale for "capability driven" elements, NASA will continue to suffer from lack of stakeholder confidence and buy-in. The separation suggested by the IWG/HEPAG truly drives a national strategy and not just a NASA-centric one.



J. Walter Faulconer
President, Faulconer Consulting Group (FCG) LLC



Mr. Faulconer is President of FCG which he founded to provide a full range of services to help customers be more successful in their strategic planning in uncertain times, win new business to grow their bottom line, and strengthen basic systems engineering and management practices for mission success. FCG provides a deep bench of advisors and subject matter experts that are supporting commercial, national security, and civil space clients.

Walt is currently a member of the NOAA Science Advisory Board and the Executive Secretary for the Department of Defense Strategic Capabilities Office Advisory Group. He manages NASA's Flight Project Development Program to develop the next generation project managers and leaders. Previously he served as a past Executive Vice President of the American Astronautical Society and on the Constellation Program Standing Review Board for NASA.

From 2005-2010 Walt was the Business Area Executive for Civilian Space at the Johns Hopkins University's Applied Physics Laboratory. His responsibilities included managing all aspects of the Civilian Space Business Area. Programs included the development, launching and operations of the NASA New Horizons mission to Pluto, the MESSENGER mission to Mercury and the twin STEREO spacecraft to study the sun. Mr. Faulconer's leadership helped to develop a backlog of new and exciting NASA science missions including the twin Radiations Belt Storm Probe satellites that were launched in 2012, the Parker Solar Probe mission launched in 2018 and the Europa Clipper mission to be launched in 2023. He instituted important quality, management, and safety practices in support of APL achieving its AS9100 certification.

Previously Walt served in various capacities for 26 years at Lockheed Martin. He was the Director for Space Exploration Business Development for Space Systems Company responsible for the business development for Space Exploration including: Shuttle Return to Flight, International Space Station, and Project Constellation–Crew Exploration Vehicle - Orion. Walt's roles at Lockheed Martin included Director for Business Development for the Space Transportation line of business, including Atlas and Titan launch vehicles, and Advanced Space Transportation. He also served as director of Strategic Planning and Development for Space Systems Company, responsible for leading the strategic planning and development team. Before that, he served as the program manager for the 2nd Generation Reusable Launch Vehicle program as part of the Space Launch Initiative and supported the Space Shuttle program in payload integration, operations and astronaut training. Walt has also been a mission systems engineer on numerous national security programs.

Walt holds a Bachelor of Science degree in Space Sciences from the Florida Institute of Technology and a Masters degree in Systems Management from the University of Southern California.

Chairwoman HORN. Thank you very much, Mr. Faulconer, and thank you to all the witnesses for your opening statements. I know we have a lot to discuss today, and I'll start with questions and then we'll go from there.

So the Chair recognizes herself for 5 minutes for the first round of questions if I can find my questions, that is. Here they are.

So, Mr. Gerstenmaier and Mr. Sirangelo, thank you for being here. I think was a great reminder that the Full Committee Ranking Member played that video. There's a lot of really important and inspirational things that NASA has brought to us that each of you has touched on.

So I have a series of questions because we've got to get this right for so many reasons that many of you have mentioned.

The NASA Administrator committed to providing the Committee with an amended budget request very close to April 15, so it's now May 8, and my question is what is the reason for the delay, and can you commit to providing this Committee with a lunar plan and budget amendment on what date?

Mr. GERSTENMAIER. I guess I can start. I think, first of all, we recognize that this is a really serious challenge we have to lay in front of us, and we need a really solid plan. And it was discussed by many of the testimonies here. We need to make sure it's all integrated and all put together in a way that really makes sense.

So we've been taking the time. We brought Mark on board. He's been working with us. We've been working to develop detailed plans building off of what we've already done, so we're taking a lot of the equipment that we've already been doing, the teams we've had in place, and we're figuring out how to use those in a new, creative way moving forward. So we're busy establishing those plans.

We also have to go through the Administration, get budget approval, make sure we understand where we are, even look at the out years because if we work just near-term and we think about just the next year and we don't have those future plans all the way through 2024, answer some of your questions about how the "why" fits in, and then how this feeds to Mars, we need to put all that together. So we're taking the time to get that right.

We're probably several weeks away, maybe 1 week to 2 weeks away from being able to give you a plan and show you what we have moving forward with specifics. But we can—at a high level we can describe to you today some of the things that we're doing and moving forward and how we build off of the existing programs.

Chairwoman HORN. Mr. Sirangelo, do you have anything to add to that?

Mr. SIRANGELO. Thank you for the question. It's a serious question, and we take it that way. This isn't just about moving a date forward. It's about trying to figure out how to do something different and better at the same time. The process that we've gone through is to make sure that the architecture that we need to design makes sense.

One of the—I think the highest things we have to do for this Committee and for Congress is to come back with answers that we can really believe in that we can speak to, and those are in the works. We have gone through the architectural design, we've gone through the understanding of what it's going to take to make that

happen, but it's also more than that. How does NASA change? How does NASA organize? How do we incorporate the commercial and other parts of our industry to enable this?

I think, as Bill said, we are well on that way to doing it. We also have an obligation to make sure that we work together with the budgeting process. So from our perspective at NASA we're very close to doing that, and we understand that the delay is frustrating, but this is a big challenge and we want to get it right.

Chairwoman HORN. So thank you very much. It is a big challenge, and we absolutely have to get it right, which is why we need detailed plans and proposals. We'll look for that in a couple of weeks. And I think, as Ranking Member Babin and Chairwoman Johnson mentioned, there will likely be follow up within this Committee on that issue.

So following up on those questions about these plans because sustainability and long-term planning is critical for something that is this challenging and this important, who in the Administration will have final approval and signoff on the plan? And who in the Administration will have final signoff and approval on the budget amendment?

Mr. SIRANGELO. From the NASA perspective, the NASA Administrator is responsible for the plan and for the delivering of the plan. We are supporting that. The budget is then provided as an estimate to OMB, and OMB would then provide the budget when it's thoroughly completed it.

Chairwoman HORN. OK. Thank you. So what—and following up further, what acquisition approach—when you're looking at this, what acquisition approach is NASA planning to use to procure the elements needed for the 2024 lander? Are you looking at firm-fixed price, cost-plus? What is the approach that you're looking at right now?

Mr. GERSTENMAIER. I think we're looking kind of at a mixture of approaches depending upon the hardware and systems that we put together. We've been using broad agency announcement called BAAs that have been pretty effective. They're typically a contracting instrument that has a fixed-price provision in them. I think there's also a role for some cases to have some cost-plus activities, but I think you'll see a mixture of acquisition approaches moving forward depending upon the risk level, the speed, and the maturity of the industry.

As you see, we talked—Mark talked a little bit about the commercial lander services program that the Science Mission Directorate is doing. That's a small lander system that—when we land small payloads on the Moon. We'll get a chance to see how that works in the Science Mission Directorate where they can take significantly more risk than we can. And depending on how well that works, we can get a chance to judge how ready industry is to go take on the challenges of human-class landers. So we'll use these acquisitions to inform other acquisitions moving forward, but it's a variety of acquisition instruments.

Chairwoman HORN. Thank you. And will the acquisition approach be included as a part of the plan when you submit it?

Mr. GERSTENMAIER. Yes, at a top level, and we're actually implementing some of that acquisition approach today as we sit here.

Chairwoman HORN. OK. I know I am a little bit over time. I'm just going to—have a couple more and then we'll turn it over to Ranking Member Babin.

Will—so will NASA—my next question is about authorities because there have been a few things. Will NASA be seeking any statutory authorities to achieve this 2024 Moon landing level in the overall program, and if so, when do you plan to provide those to the Committee?

Mr. GERSTENMAIER. They would be provided when we provide the overall plan to you.

Chairwoman HORN. OK. I mention this because I want to note that the reason that I question this is that the approach of using a reprogramming request rather than going through the authorizing committee to propose major reorganizational changes, especially since NASA still—we don't have the plan yet, and it hasn't been provided to the Committee with any specific plan changes or budget amendment to evaluate it, and the request to the Appropriations Committee takes that approach.

Following up, do you have any—do you have a lunar—and I think this is—we've seen—you know where I'm going—questions about this. Do you have a lunar surface spacesuit that will be ready for the 2024 mission right now? If so, which suit is it? And if not, when do you anticipate that being available?

Mr. GERSTENMAIER. We don't have a suit that's appropriate for the activity for the Moon today. We have portions of the suit that are sufficient but not the entire suit. Again, we're going to understand the test that we want to do on the first mission in 2024 and then, based on that, we're going to probably develop a suit to move forward in that direction.

In the past, we started suit activities before. We did it in the Constellation program. That suit cost for that program became very prohibitive. We need to look at a way that we understand the requirements and we incrementally move forward and build off of what we've got, so we need to do some work, and that'll be discussed again. And there's a plan is—will—there will be a discussion of the plan for suit acquisition as part of the overall lunar plans moving forward.

Chairwoman HORN. Thank you very much. I know we'll have many more questions for the rest of you. For now, I'm going to wrap that up.

And I recognize Ranking Member Babin.

Mr. BABIN. All right. Thank you. Thank you very much.

I guess, first, I want to recognize two interns from Texas A&M University we have out there in the crowd. Josh Mendez back there and Rachel Gill in the back as well, thank you for being here.

In 2011, this Committee held a hearing entitled, "NASA Human Spaceflight Past, Present, and Future: Where Do We Go from Here?" Former NASA Administrator Mike Griffin testified, and I'd like to quote from several passages from his testimony and seek very brief yes or no answers from our witnesses. And if you would like to elaborate more, please wait until the end.

So to start, this is, quote, "What does a real space program look like and not look like? A real space program sets and meets stable national strategic goals for the leadership on the space frontier by

developing, evolving, and preserving national capabilities to operate on that frontier. It does not allow that capability to be held hostage to the goodwill of other powers or to the vagaries of a nascent and fragile marketplace." All very briefly, I would like to go down the line, start with you, Mr. Gerstenmaier, do you agree with this sentiment, yes or no?

Mr. GERSTENMAIER. Yes.

Mr. SIRANGELO. I do.

Dr. LUNINE. Partially, I agree.

Dr. SANDERS. Yes.

Mr. FAULCONER. Yes.

Mr. BABIN. Thank you very much.

All right, second, "A real space program may", I'm still quoting, "and, indeed, should offer a stable market to be addressed by commercial providers, but it cannot be dependent upon such providers for strategic capabilities. A real space program recognizes that this Nation has interests that rise above the fortunes of individual private contractors, and it protects those interests. The proper role of government is to reward winners, not to pick them, nor to step in as an investor in enterprises which cannot pass the test that the capital markets impose."

Mr. Gerstenmaier, yes or no, do you agree with that?

Mr. GERSTENMAIER. Yes.

Mr. BABIN. Mr. Sirangelo?

Mr. SIRANGELO. Yes, I do.

Mr. BABIN. Yes, sir. Dr. Lunine.

Dr. LUNINE. I agree with that statement.

Mr. BABIN. OK.

Dr. SANDERS. Yes.

Mr. BABIN. Yes.

Mr. FAULCONER. Yes, I agree.

Mr. BABIN. All right, thank you.

Going on, a real space program is grounded in physics, not politics, and stepping outward beyond low-Earth orbit and the ISS a human return to the Moon is the next logical goal from a host of scientific, engineering, operational, and even commercial perspectives. From there, and with the experience thus gained, we should proceed onward to Mars, and should do so in a timely way, else Mars will always be the destination in the future.

Mr. GERSTENMAIER.

Mr. GERSTENMAIER. Yes.

Mr. SIRANGELO. Yes, I do.

Dr. LUNINE. Absolutely.

Mr. BABIN. Dr. Sanders?

Dr. SANDERS. Yes, with a caveat.

Mr. BABIN. OK. Well, if I have time at the end, we'll hear about that.

Mr. FAULCONER. I agree.

Mr. BABIN. All right, thank you.

And then finally, these truths were recognized in the *NASA Authorization Act of 2005*, and again in 2008, both of which were originated by this Committee. The course for this Nation's future in space that was laid out in those Acts does not need to be changed, it needs to be followed. We must stay that course. If we

do so, the right rocket designs will emerge. If we cannot, the rocket design doesn't matter.

Concerning the larger perspective of this hearing, I can thus offer no better counsel to this Committee than the guidance which it has previously issued.

Mr. Gerstenmaier, do you agree?

Mr. GERSTENMAIER. Yes.

Mr. BABIN. Mr. Sirangelo?

Mr. SIRANGELO. I do.

Mr. BABIN. Dr. Lunine?

Dr. LUNINE. I do.

Mr. BABIN. Dr. Sanders?

Dr. SANDERS. Yes.

Mr. BABIN. Dr. Faulconer?

Mr. FAULCONER. Yes.

Mr. BABIN. OK. Now, we still have about an—1 minute and 6 seconds left, would any of you like to elaborate further on these? Dr. Lunine?

Dr. LUNINE. So first, I'd like to know if I passed the pop quiz or not, being a professor. Second, my one caveat with the first question was that it is crucial that we engage other agencies of other countries in any program going to Mars. The cost of the undertaking is going to be such, and the magnitude is going to be such that not engaging with international partners, I think, would be a mistake. Certainly, we should be leading, and we need to lead from the front, not from behind, but I just want to make clear that international participation in sending humans onto Mars is crucial.

Mr. BABIN. Do you think that those international partners should be on that critical path as well?

Dr. LUNINE. I think that the answer for Mars at least, not necessarily for the Moon, but for Mars the answer is yes, in my view.

Mr. BABIN. Dr. Sanders?

Dr. SANDERS. The statement said that the space program should be physics-based and not politics-based, and I agree that the solutions, the technical means, are physics- and engineering-based, but sometimes the reason why a program is important is—has to do with national goals beyond the technical goals.

Mr. BABIN. I would agree. I would agree. Thank you very much.

And I think my time has expired, so I want to thank you all, witnesses. And I yield back, Madam Chair.

Chairwoman HORN. Thank you, Mr. Babin.

The Chair now recognizes Full Committee Chairwoman Johnson for 5 minutes.

Chairwoman JOHNSON. Thank you very much.

I'm just filled with questions, and I know there's not time to answer all of them, but I am very impressed with all of the research that's going on now with NASA, and I'm very concerned that much of it might be interrupted to afford the new direction. And I need your opinions on that. Could you start, and just go down the line?

Mr. GERSTENMAIER. Sure. I think do we need the—we need to invest in new research and new technology to achieve the kind of goals for Mars. So we need to balance the near-term urgency with the need to do the investment into long-term research and science and technology development.

Chairwoman JOHNSON. Does that include discontinuing or slowing down substantially the type of research that's going on now at NASA in Maryland?

Mr. GERSTENMAIER. We should not slow down the research that's—that fits our objectives moving forward. It needs to continue in parallel. And we can use some of that research directly in what we're doing. I think Space Station is a great example. The OCO-3 experiment, the carbon experiment, is going to station. It'll be installed Thursday night. That was a spare instrument that was available on the ground that was able to go fly from Goddard up to Space Station, and it essentially takes advantage of Space Station. So the human spacecraft has essentially provided a home for this instrument that's going to give us a new look at carbon generation that we would not be able to see without the tie between human and research.

Chairwoman JOHNSON. Um-hum.

Mr. GERSTENMAIER. So I think there's not a—necessarily an incompatibility between the two objectives.

Chairwoman JOHNSON. What is the future of the Orion, of the SLS?

Mr. GERSTENMAIER. They look strong. We've got a lot of work in place. As I described in my opening remarks, there's a lot of hardware in place, a lot of hard folks working on that hardware. We're in the middle of very heavy integration down at the Kennedy Space Center with Orion. We're in the final construction of the core stage at Michoud Assembly Facility in New Orleans—outside New Orleans. It's a very busy time for us; turning kind of dreams, aspirations into real hardware that will take us to the Moon and on to Mars.

Chairwoman JOHNSON. Thank you.

Mr. SIRANGELO. I agree with Bill's comments, but I want to take it one step further because I think your question is really an important one.

As a technologist, one thing to do is to develop the technology. The second part of it is to actually put it into service, to make it work. And I think one of the aspects of this program, by accelerating what we actually are doing, is enhancing the science. We're not just doing the technology, doing the science in theory, or in prototype, but we're bringing it to a place where we can actually use it, make it better, and bring it back and improve it for the next generation. And that's a really key and critical part of what we're trying to accomplish.

I think the other thing which is really important on this plan is that by going and getting ourselves in service by 2024, what we actually are doing is then starting operations in 2024 going forward, many years sooner than what we would have done. And it's in that operational phase, it is in that ability to continue to move forward that we really see the strides that are necessary.

If you go back and look at any part of our history in aviation, the difference between the airplane when we entered World War II and when we came out of World War II was incredible. The difference in the airplane when we entered World War I and we came out of World War I is incredible. And I think what we're seeing here is this opportunity over the next 5 years to enhance that

science, to bring it to the next level, and to put it out in the field where it can do some good, is really the difference-maker because that's what creates the jobs for the future, that's what takes that technology and makes it useful for the American people.

Chairwoman JOHNSON. Thank you.

Dr. LUNINE. Thank you, Chairwoman Johnson. It's a pleasure to be testifying in front of you again.

With respect to research having to do with space science, as you mentioned Maryland, there are places that robots can go that humans cannot. Our committee was serious about Mars being the horizon destination for a number of reasons. NASA's spacecrafts have gone out through the whole solar system, have looked at the universe, virtually to the end of the universe, and those kinds of discoveries must continue as we continue to develop this human spaceflight capability. Having said that, there are things that robots and humans can do together on the Moon and Mars that will open up a whole new dimension of science and exploration if we can implement that kind of dual approach.

Dr. SANDERS. NASA's portfolio is a lot bigger than just human space exploration and deep space exploration. There's a lot of Earth science work that's very important to a lot of our Nation. There's very deep space probing sensors that we'll see with the James Webb Space Telescope when it get—and the first A in NASA aeronautics, what they're doing with low-boom technology and other things, that shouldn't go away just in order to make this one happen.

Mr. FAULCONER. So coming from the Johns Hopkins Applied Physics Laboratory in Maryland, I am very much concerned about the science portfolio as well. But I think it's healthy, and if you look at the portfolio, there's a great raft of missions being planned. And I agree with Mark that I believe that this initiative will actually help us accelerate not only the science missions, but also the technology that will then benefit the science missions.

Chairwoman JOHNSON. Thank you very much. My time has expired.

Chairwoman HORN. Thank you, Chairwoman.

The Chair now recognizes Full Committee Ranking Member Lucas for 5 minutes.

Mr. LUCAS. Thank you, Chair.

Mr. Faulconer, the Vice President has challenged NASA to return to the Moon by 2024. Your testimony indicates this is the appropriate course for NASA to pursue. Based on your experience with other programs, let's talk for just a moment about the greatest challenges to achieving the goal, and how we can mitigate those challenges.

Mr. FAULCONER. Well, as I mentioned, the institutional momentum was one issue, but another one I agree with Dr. Sanders about is the consistency of purpose. You know, quite honestly, a lot of us in this industry suffer from professional whiplash because every few years we change what direction we're going, and where we're going, and how fast we're going. We need that consistency of purpose so that we can stay focused. And so I—that's one reason why I welcome it's logical to go back to the Moon and get on to going to Mars.

Mr. LUCAS. Mr. Gerstenmaier and Mr. Sirangelo, speaking of that, President George H. W. Bush's Space Exploration Initiative was challenged by a $400 billion price tag, which Congress at the time rejected. President George W. Bush's vision for space exploration was challenged by a lack of support from OMB, which failed to request sufficient funds to support the plan. We've made considerable progress since those two proposals. NASA's exploration budget now eclipses $10 billion per year, and we're invested in the Space Launch System, the Orion Capsule, and the supporting ground infrastructure. We've already made investments in next-generation systems that are necessary for lunar exploration and a steppingstone to the Moon. What's NASA doing to implement lessons from those previous initiatives, and specifically, what is NASA doing to ensure that any plan it submits to Congress for review is sufficient, that being a very key phrase, sufficient to achieve the goal, but also focusing only on the necessary investments?

Mr. GERSTENMAIER. Again, I think as we take a look at the lunar objective for 2024, again, as I described kind of in my opening testimony, we're taking the hardware we've already built that's already in pieces, and we've figured out how to implement that hardware to go to achieve the lunar goal. And the discussion about the spacesuits, again, we've got to be careful we don't put more than we absolutely need for the suits, for the missions to begin with, but they're evolvable and they're sustainable moving forward.

So I think we need to take this in steps, the way it's been described where we put pieces in place, that we can build and build the next piece moving forward.

The ascent vehicle that we'll look at for the lunar activity, that ascent vehicle has direct applications to the Mars ascent vehicle on Mars. So if we look at where our hardware fits and how it moves forward, we don't have dead ends, we don't build hardware that's unique to one application and move forward. And we need to be very cautious about how we build our contracts, how we acquire our hardware, to make sure we get good value for ourselves, and to continue to do the right—or don't drive the budget to the levels that are not sustainable.

Mr. SIRANGELO. Sir, I think one of the things that is really different this time is that we are—when you're investing in technology as the way we have done as a government and as a country, it's an accumulative process. We are a lot smarter not only because we've learned the lessons of the past, but because we now are—exist in an industry that has significantly more space flight activity, more significant, more technology on orbit, and we have just understood the environments that we're working in to a greatly different level.

I know in your district you have farmers who are working many generations, and in doing that you learn from generation to generation, and I think we have done the same thing in our area. We are also backed now by commercial industry throughout the United States, which has invested heavily on its own. So it isn't just government that's making that investment; we're making that investment throughout our entire economy.

Mr. LUCAS. So understand when I make this next comment, in many ways as my town meeting constituents speak through me to

the body, I speak through you to those who make decisions. Your folks are the can-do people; but OMB, the Administration at the top levels, there are so many elements there. So when I make this following comment, bear that in mind. The previous Administration submitted budget requests that required on what I would describe as creative bookkeeping; switching NASA funding from discretionary to mandatory spending, tying it to increases in gasoline taxes. Those proposals were rejected by Congress. I hope that the proposals we'll receive are not funded in a similar fashion to the things done in the previous Administration, because that will cut the legs out from under us. If we don't accomplish this this time, I don't know when we'll have a fourth opportunity in certainly my lifetime.

Thank you. I yield back.

Chairwoman HORN. Thank you, Mr. Lucas.

The Chair now recognizes Congressman Bera for 5 minutes.

Mr. BERA. Thank you, Chair Horn, and Ranking Member Babin.

You know, I got my colleague from Colorado riled up when I was mentioning the Mars 2033 report suggested that we couldn't get to Mars until 2037, and he said he's invested a lot of time and effort into making these bumper stickers. And, you know, he made some really good points, and I think I want to touch on a couple.

Mr. Faulconer, you touched on consistency of purpose. Part of what made us successful in the 1960s was congressional support, Administration support, and a consistent goal and a consistent timeline. And I have no doubt that if we set 2033 as a goal, put the resources and focus on it, we couldn't accomplish that. What I worry about is the politics, and the politics of going from one Administration to the next. You know, you have the Constellation Program that said let's go to the Moon, and then Constellation got canceled, and we were going to go do asteroid retrieval. New Administration comes in, we're no longer doing the asteroid retrieval, we're now going to go back to the Moon. And unless we have that consistency of purpose, we won't get there by 2033.

So, you know, I'll leave it to the scientists to decide, you know, if going to—a return to the Moon is the right next step or something different, but for us to do our job and provide the support to not just NASA, and the difference today is, you know, in the Apollo Program, NASA was the launch vehicle, they were the Lunar Lander, they were, you know, the science mission. Well, today's world is much more complicated. You've got commercial launch vehicles, you've got much more robust international engagement, you certainly have the subcontractors that are out there. And when we think about going to Mars by 2033, we're not thinking about doing this by ourselves, so we really do have to then bring in that international community.

A couple of questions that, you know, I haven't been able to find answers for, but I think it would make our jobs easier as Members of Congress to advocate for that consistency of mission. We always look at programs and Congress as an expense item, and I haven't really been able to get an answer on what was the return on investment of the Apollo Mission, the number of jobs created, the number of discoveries, inventions, new companies found, what was the benefit to not just our economy, and I don't know, maybe, Mr.

Gerstenmaier, would you have those numbers, or is there a good place that you could direct those, or should we direct the Academies to perhaps do a study so it's not just the cost, but here's our return on investment that we're going to get?

Mr. GERSTENMAIER. Yes, I think that would be best if I took that question for the record, because there's been numerous studies in the past, and rather than recall those from memory, we could actually pull those, we could provide those to you, and then you could determine if they're sufficient or you want to pursue something else.

Mr. BERA. That'd be great, because again, it certainly would help us make our case. You know, we're going to spend billions of dollars, you know, both going to the Moon, but then if the goal beyond the Moon—you know, and another question that—you know, one of the opening comments, there's—you know, China is going to the Moon. They're not putting a person on the Moon. India is going to the Moon, et cetera. Our focus is to go to the polar icecaps. And, you know, one question—and I've talked to my colleague; he's a lawyer, I'm a doctor, when they—when we get there or they get there, and they start extracting some of that ice, who actually owns that ice? I mean—and, you know, I don't just put that out there, because it—you know, what are our property rights? Is it the gold rush? Is it whoever gets there first can claim that? Because in my mind, you know, we're going to think of the Moon a little bit as a gas station if we're looking at it in the context of going to Mars. We're going to take that ice, turn it into fuel, and obviously it'll be a lot easier to launch from the Moon.

I don't know if that's too simplistic, but I'd toss that out there, and whoever—anyone want to take a gander at that? Or is that the type of thing that we ought to think about proactively and set the parameters? Will this be like Antarctica where, you know, this is really an international resource for an international project? But I do—because commercial companies are already talking about trying to get there as well and, you know, is that the right question that we should be asking or thinking about, or should we be working—anyone want to take a crack at it?

Mr. SIRANGELO. I think the question is an appropriate question. When we're talking about doing the plans for what we're doing, it's not just a plan for the hardware or the technology, it's a plan to be there, which means all aspects of being there; the human life, the science, the research, but also the understanding of how to do it properly. Exploration has been going on for quite a long time in the human race, and there have been these issues before. We've sorted out those issues on the oceans. For example, there is the maritime law that handles it. So I think as we do this, it's beyond our scope today and we can't really answer the question. But I think the question is an appropriate one that we need to consider as part of our longer-term plan.

Mr. BERA. Right. And I certainly think that's a question that, you know, American space industry ought to think about, and we ought to grapple with and take it to the international community.

So thank you. And with that, I'll yield back.

Chairwoman HORN. Thank you, Mr. Bera.

The Chair now recognizes Congressman Brooks for 5 minutes.

Mr. BROOKS. Dr. Sanders, the Aerospace Safety Advisory Panel previously cited a number of safety concerns with both Boeing and SpaceX commercial crew vehicles. One item in your report cited was parachute-related concerns. Have there been any recent tests of the parachute system conducted?

Dr. SANDERS. Yes, there's actually been a large number of tests of the parachute systems conducted, both for Orion in the longer-range program, and both—and the SpaceX and Boeing commercial crew programs. And I think they've made a great deal of progress in understanding those uncertainties involved with that. It's one of the largest risks they have to solve.

Mr. BROOKS. Can you tell us about the results of recent tests, say, in the last month or two?

Dr. SANDERS. I think Mr. Gerstenmaier probably could do a better job with that, but there have been a number of very positive tests, results confirming that—what we would expect or would desire in terms of re-entry performance of the parachutes. There have been a few less satisfactory results, and some tests that are indicating that there may need to be some redesign or some adjustments made to the design that they have as now. And those are important to get right before you launch humans.

Mr. BROOKS. More specifically then, did SpaceX conduct in April 2019 a parachute test in Delamar Dry Lake, Nevada?

Dr. SANDERS. Yes, I believe.

Mr. BROOKS. And what happened in that test?

Dr. SANDERS. I cannot answer that right now. Mr. Gerstenmaier might have better data than I have at the moment.

Mr. BROOKS. Mr. Gerstenmaier, do you know what the result of that test was?

Mr. GERSTENMAIER. Yes, the test is going to force us to go back and look at some potential—well, I—we're not sure exactly. The test did not—was not satisfactory. We did not get the results we wanted, but we learned some information that's going to affect potentially future parachute designs. The other thing we need to understand, was it a test-unique circumstance? Was it driven by an actual design problem in the hardware, or was it driven by the set-up of the test or the particular equipment that was used during the test?

Mr. BROOKS. Can you get more specific when you say it wasn't what we wanted?

Mr. GERSTENMAIER. Yes, it didn't fail—it failed. The parachutes did not work as designed. It was a one single-out test for this parachute, so typically that test would involve four parachutes. One was—proactively failed ahead of time, and then the three remaining chutes did not operate properly.

The good thing on the test was we had instrumented lines going up to the parachute, so we know exactly what the loads were in the system, but we still need to understand whether it was a test set-up configuration coming out of the aircraft, or if there was something associated with the packing of the parachutes, the rigging, all that. But this is part of the learning process. By these failures, we're going to learn the data and information to effect a design, to end up with a safe design for our crews.

So I don't see this as a negative. This is why we test. This is why we want to push things. This is why we want to learn——

Mr. BROOKS. What was the impact on the vehicle of the parachute failures?

Mr. GERSTENMAIER. It was a test sled, and the test sled was damaged upon impact with the ground.

Mr. BROOKS. And you're comfortable that corrective measures will be undertaken?

Mr. GERSTENMAIER. There's no question. I am very comfortable. Their teams are fully engaged. We are understanding this is a gift to us. We have—we've gotten data that is unique that will help us design and understand if this is something that needs to be fixed, or if it's something that was just a nuance of the test and the configuration. And the——

Mr. BROOKS. All right, let me——

Mr. GERSTENMAIER [continuing]. NASA teams are fully engaged in——

Mr. BROOKS. Let me move on to another one because I've only got 60 seconds left.

Mr. GERSTENMAIER. The NASA teams are fully engaged in——

Mr. BROOKS. The goal, as I understand it from the Vice President, is to reach the south pole of the Moon by 2024. Can any of you tell me what the additional cost will be, or appropriations needed by NASA in order to achieve a landing on the south pole of the Moon by 2024?

Mr. SIRANGELO. Not at this time, sir. We are—we have provided preliminary estimates to OMB. OMB is reviewing those along with our CFO, and that information is imminent.

Mr. BROOKS. What is the preliminary estimate?

Mr. SIRANGELO. I'm sorry, sir, we can't—right now it is under review, and we can't come up with a number.

Mr. BROOKS. How would it be paid for? Where would the money come from?

Mr. SIRANGELO. That's why we're not here today to be able to speak to the money side of the equation because at this point in time there's—it's still under discussion with OMB and NASA.

Mr. BROOKS. And do you have a judgment as to when we will know what the requested amount of additional budget will be?

Mr. SIRANGELO. That will come when OMB releases it. We've provided the information. I will say there have been significant discussions. The discussions have been very positive and open, and as soon as those discussions are complete and OMB has approved the numbers, they'll provide it to you.

Mr. BROOKS. Thank you, Madam Chair.

Chairwoman HORN. Thank you, Mr. Brooks.

The Chair now recognizes Congresswoman Hill for 5 minutes.

Ms. HILL. Thank you, Madam Chair. And thank you all for being here.

A couple of questions. For NASA's deep exploration systems, nearly 4,000 employees in California supplier companies work on SLS, Orion, or the Exploration Ground Systems, which is the largest supplier workforce of all 50 States. These programs are, of course, critical to our national space exploration program, and engineers, technicians, and software programmers in my district help

contribute to the space program and our return to the Moon and beyond.

The Chairwoman already mentioned acquisition. I know you've spoken about it some, but I'd like to learn more about how NASA will utilize existing contracts and supply chain infrastructure in getting to the Moon by 2024, and beyond to Mars.

Mr. GERSTENMAIER. In the case of SLS and Orion, we're—and Exploration Ground Systems, those contracts are—we're completing the design phase, and then we're going to go into production and operation. So we're starting to put out requests for proposals for sustained cadence of buying those vehicles, and we're looking for ways to buy multiples of the vehicles at one time to get a more effective cost plan for us. And that also allows industry to then plan for a more stable workforce moving forward.

Ms. HILL. Great. Mr. Gerstenmaier and Mr. Sirangelo, I understand that NASA believes there are a small number of basic elements needed for the 2024 lunar landing, a power and propulsion element, a small habitat, and an Integrated Landing System. Given the rapid timeline in which work would need to occur to meet the 2024 deadline, can you please explain a few things? What are the dates when each of these elements will be on contract?

Mr. GERSTENMAIER. We've received proposals for the power and propulsion element. Those are being evaluated now by the NASA teams, and it should be probably by this summer we should make an award or awards for that activity, for the power and propulsion element.

The mini habitation piece that will need to be on the Gateway, that's still kind of an early acquisition. We're going to go through acquisition strategy meetings at the agency probably in the next couple of weeks, then we'll be ready to go out with some kind of activity.

For the lander systems, we've done a synopsis already for the descent portion, the transfer vehicle, and the refueling piece. We've received proposals for those. We're evaluating those now. Probably again, in probably a month or so we're ready to go make some awards for study phases for that.

And then we just recently dropped a synopsis out which looks at the entire Integrated Landing System from Gateway down to the surface, and the surface back to Gateway. After we receive comments to the synopsis, we'll put out an instrument—a broad agency announcement to go acquire that. And that's probably also within about a month or two.

So in probably 2 months, all the pieces necessary to get to 2024 will be in some serious study phase, or will be in serious acquisition for the hardware and systems to move forward.

Ms. HILL. OK. You're in agreement, Mr. Sirangelo?

Mr. SIRANGELO. I am in agreement. I would also add that what Bill has been speaking to represents a substantial utilization of the American industrial base to make that happen. And the idea of being able to contract this out, and contract this out in this rapid fashion, is one of the benefits of being able to move forward quickly, is to make sure that industrial base stays strong and stable, and that we have access to that for the long-term.

Ms. HILL. So that relates to would either NASA or the contractor be willing to provide Congress with a clear understanding of the details of the contracts? So, you know, who would be responsible for cost growth and development or testing, the government or the contractor, and what's the timeline involved in the test program, et cetera, et cetera?

Mr. GERSTENMAIER. We can provide that when we get to that phase, or when the plan comes out we can describe that to you.

I think the thing that's important is in the past NASA had to do all of this development on its own in the Apollo era. What's really unique now is industry is very capable of doing some of these things, and we need to utilize industry where we can and take expertise from industry, and work approaches where we share risk with them, we share acquisition approaches with them. We're doing that in the Commercial Crew Program that we just discussed where there's a shared accountability for resources and for safety kind of aspects, and we're working those. And we'll build off of what we've learned in the Commercial Crew Program, and take that forward as we go to the lunar systems.

Ms. HILL. Thanks. So I guess the final question then, we're almost 6 months into 2019, and elements are going to need to be, of course, completed months in advance of the launch to enable integration and with the launch vehicles and preparations. How much real confidence do you have that a human landing on the Moon in 2024 is achievable?

Mr. GERSTENMAIER. I think it's very achievable. The challenge will be can we get through the political process, can we get the political stability, can we get the funding necessary to go do this in the timeframe to move forward, can we get any legislation relief that we might need, and get a clarity of purpose, can we get united in this goal enough to move forward at the pace that we'd like to go. That'll be the biggest challenge.

Ms. HILL. The money my colleague was talking about.

Thank you all so much. I yield back.

Chairwoman HORN. Thank you, Congresswoman Hill.

The Chair now recognizes Mr. Posey for 5 minutes.

Mr. POSEY. Thank you, Madam Chair.

It was great to see that NASA has provided recently a roadmap to go back to the Moon by 2024. Great step toward getting to Mars. Exciting that it's finally happened. To achieve, you know, the ambitious timeline, I think that we all agree that we need to ensure that there's, number one, sufficient funding to get that done. We've had a diagram of missions to nowhere. I think we had over 2 dozen different missions, over $20 billion up in smoke, because we couldn't stay on one plan from Administration to Administration, Congress to new Congress.

Both the Administration and Congress should continually fund our critical space assets, such as the SLS, Orion crew vehicle, Exploration Ground Systems, Mobile Launcher 2, and the Lunar Orbital Platform, obviously.

Mr. Gerstenmaier, can you, without getting too deep in the bushes, just give me a little brief summary of the benefits of an SLS Green Run.

Mr. GERSTENMAIER. OK. So I think that the simplest advantage is that it allows us to see the integrated system work is an integrated system. The engines actually pressurize the tank for the Space Launch System, and that's a very complex mathematical model of how the cryogenic propellants and things interact, and the really—way to see all that is in a full-up integrated test. You can test individual components but you can't test it as an integrated system, as well as you can, for a fairly long duration, test through the Green Run.

Mr. POSEY. OK.

Mr. SIRANGELO. I would add to that that what this test essentially is, is a full-run test of the system. We're going to take humans; Americans, and put them on top of this rocket. We want to see the system work for its full duration burn, and the best way to do that is to conduct a full-duration burn before we then integrate the rocket and put people on top.

Mr. POSEY. OK. Mr. Sirangelo, in order to support the 2024 launch date of the SLS with the Exploration Upper Stage (EUS), NASA needs to award a contract for the second Mobile Launcher at Kennedy Space Center. The Administrator mentioned that the contract is likely to be awarded in May, and I wonder if you can provide us with a status update on both the EUS development and the schedule, as well as when the contract will be awarded for the second Mobile Launcher.

Mr. GERSTENMAIER. I can help. We're ready, we're poised to go ahead and make the award for the Mobile Launcher as soon as the teams do the evaluations. So that award is on track and it will be either this month or next month, but it's on track moving forward.

And then the Exploration Upper Stage, we slowed things down a little bit. We're running it at a slower rate this year for the Exploration Upper Stage. We went from 300 million down to 150 million expenditure this year for the Exploration Upper Stage. That was so we could focus on Exploration Mission-1 on the core rocket to make sure that the teams and the equipment and effort are getting ready to go support Exploration Mission-1.

Mr. SIRANGELO. I would add to that, sir, that one of the aspects we wanted to make sure the Committee understands is that work has not stopped because we've changed the date. We've continued to push forward on many elements of the program. We continue to look to award, and you'll see several awards coming off in the next quarter. So as we go forth and try to look at the plan and find ways to accelerate it safely, we are also keeping elements of the program which are not going to be affected moving forward.

Mr. POSEY. Thank you very much. Madam Chair, I yield back.

Chairwoman HORN. Thank you very much.

The Chair now recognizes Mr. Beyer for 5 minutes.

Mr. BEYER. Thank you, Madam Chair. And thank you, guys, very much for being here with us today.

On the NASA thing, you talked a number of times about international partners. Could you talk more about who those international partners are? Will they be China, will they be Russia, or is this typically France and the U.K., or what's left of the U.K.?

Mr. SIRANGELO. We have a number of international partners who have been working with us on the Space Station for many years.

That includes the European Space Agency, the agencies within Europe, Japan Aerospace Exploration Agency, Canadian Space Agency, and others around the world. We expect to continue those relationships and move them forward.

Mr. BEYER. But not China? Despite how prominent they are in *The Martian*.

Mr. SIRANGELO. Currently, we're precluded from having those discussions, sir.

Mr. BEYER. Yes. I was fascinated by the notion that one of the driving forces for thinking about Mars was thinking about the long-term sustainability of the human race. And if any of you would like to specifically address that idea of building as many alternatives into our possible human future, and how the Moon-Mars mission builds upon that.

Dr. LUNINE. So, Congressman, I'll try to address that. In our Pathways report, we talked about the various reasons for human spaceflight, both practical and aspirational, and one of them is the aspiration not only to explore, but for humans to become a multi-planet species at some point.

We recognize though the realities of humans living entirely independently on a planet as inhospitable as Mars, and so we put the two planet species rationale as an aspirational one rather than a practical one, in the sense that I don't think anybody is at all under the misapprehension that by putting a base on Mars we would avoid human extinction should some planet-wide catastrophe occur on the Earth. I mean very quickly the Mars colony itself would also go away. So we must take care of our own planet in order to ensure that we can survive as a species, but in living on another planet and having the aspiration and the goal to do that, I think it will change our perspective as a species and perhaps lead to a future that we might not otherwise be able to imagine.

Mr. BEYER. But you do talk about living off the land as an aspirational goal also.

Dr. LUNINE. Yes, we do in the report. That's right.

Mr. BEYER. But is this also part of the energetic search for exoplanets that resemble Earth?

Dr. LUNINE. So that search is, of course, going on independently of the Human Spaceflight Program. Within our—I think within the understanding today of technology and the human condition, the ability to sustain humans beyond Mars is something that doesn't seem practical, and the primary issue is that there's a type of radiation: Galactic cosmic rays, which are very, very difficult to shield against because they're very high energy, and so they produce secondary particles when they collide with spacecraft and with shields. So that's one of the reasons why Mars is the horizon goal.

Sending humans to other planetary systems around other stars is something that one can imagine, but the practicalities of it, I think, are beyond us at this point in time. That doesn't mean we should not be looking for other Earths, because that again, if we find them, will change our perspective on what our place really is in the universe.

Mr. BEYER. I would imagine the excitement has to be too if there are other Earths, is there also then other intelligences.

Dr. LUNINE. That's one of the great questions not only of science but of humankind. Are we alone in the universe, and are there other sentient self-aware beings that we can ultimately communicate with.

Mr. BEYER. Dr. Sanders, you talk about the overall risk-benefit equation, you know, how safe is safe enough. Who determines that equation?

Dr. SANDERS. Anyone who makes a decision on accepting risk. When NASA—and usually that's done at a fairly high level in NASA, in the administration, depending on how much risk it is and what the specific causes are. But it's a decision that our panel has advocated and strongly recommended that always be documented, which we always say, you know, what are the alternatives you looked at, what was your rationale for deciding that you're ready to accept that risk and that there isn't another—a safer alternative, and the—and what do you expect to gain by going forward with that risk.

Mr. BEYER. Great. Great. Thank you very much.

Madam Chair, I yield back.

Chairwoman HORN. Thank you very much.

The Chair now recognizes Mr. Olson for 5 minutes.

Mr. OLSON. I thank The Chair. And welcome to our five witnesses.

I'd like to start out by talking about a hero of mine and probably all of yours, a man named Gene Cernan. Gene is the only American to go to the Moon twice. Did that in Apollo 17, when he landed, walked on the Moon, our most recent moonwalker, and also Apollo 10, the flight that did everything Apollo 11 did except for land. Gene was here in this very room in 2009 when this Committee, in a bipartisan manner, fought to save the last mission to go to the Moon. It was called Constellation. We saved the crew capsule in that battle, but Gene was very adamant the best reason to go to the Moon is because that's the best place in the universe to train for going to Mars. He pointed out a few things. First of all, the gravity. The Moon is about one-sixth of our gravity. Mars is one-third of our gravity. To train up there, it's much better training than in a pool outside the Johnson Space Center. It's real training. In fact, the first steps on the Moon were steps, they started hopping, they realized I can hop quicker and go places quicker by hopping instead of walking. He also pointed out that we found out long after he left the Moon there is water on the Moon. He said we don't know what we don't know about the Moon.

And it sounds like all of our panelists agreed that the Moon is a good starting point to go to Mars. In fact, I think the quote from you, Dr. Lunine, was the Moon is a stepping stone for Mars. And, Brother Gerstenmaier, you said it's a proving ground for Mars.

So could all of you go into detail about the benefits of us going to the Moon to get us to Mars as quickly as possible? How is the Moon tied directly for us going to Mars? Gerst, you're up first.

Mr. GERSTENMAIER. I think first of all that the Moon is a—in a proving ground sense is a great place for us to check out the technology to go beyond the Earth Moon system, to build the rockets that need to go there, they can have application moving forward, we can test them and check them out.

It's also good from a risk standpoint. Today, we're very comfortable in low-Earth orbit where, if something goes wrong on station, we can be back in an hour or so, hour and a half. When we go out to the Moon, we're now 5 days away. That's a challenge, but it's not months away like it is when you go to Mars. So learning how to operate, build the procedures in, build the stuff that the control center folks do in Houston, and understand how to operate around the Moon will be absolutely critical to build those skills, to build the technology and prove it before it absolutely positively has to work as we go toward Mars. And I think it's a—it's very strong in that sense.

Mr. OLSON. Mr. Sirangelo, sir. Thank you, Gerst.

Mr. SIRANGELO. Thank you, sir. I would add to that that one of the best things that one needs to do in order to get good at something is to practice, and to practice consistently. Being able to be 5 days away, being able to make the missions that we're doing, and to be able to do them in a frequency that we can actually learn, develop, reiterate, improve what we're doing and do it again, allows us to get much better, much sooner.

So being able to go to the Moon and doing all the things that we've been talking about for the last 2 hours is very good. Being able to do it on a frequency that we can actually take the things back and do it better really makes it a much more feasible and practical path. And what it does is actually gets us to Mars sooner rather than later.

Mr. OLSON. Thank you. Dr. Lunine.

Dr. LUNINE. Lunine. Yes, thank you.

Mr. OLSON. Sorry about that.

Dr. LUNINE. No, thank you, Congressman. So a number of technologies, as Mr. Gerstenmaier mentioned. Radiation safety, if we spend a long time on the surface of the Moon we're going to have to deal with shielding, that will also be critical for transits to Mars. The environmental control and life support systems for long-term stays on the Moon will also be applicable directly to Mars. We talked about habitats as well. We talked about crew health. And aspects of in situ resource utilization, even though on Mars it would be primarily for the atmosphere, there are aspects of it we would use—we would test on the Moon.

And let me also say that successfully using the Moon as a stepping stone, bringing humans back there, working and exploring on the Moon provides a success that the public will see and recognize as a critical moment, that will then project us on to Mars. And we made that point in the report, but let me say personally, as a 12-year-old watching—13-year-old watching Gene Cernan and Harrison Schmitt in the last Apollo mission, exploring the Moon for 3 days, I felt inside of myself that we were going on to Mars, and that I would be a part of that. And even though we're here almost 50 years later and we're not on that journey, going back to the Moon, working on the Moon will create that same sense that, yes, we can do that for Mars that I felt back in 1972.

Mr. OLSON. Thank you, sir. I'm sorry, Dr. Sanders and Mr. Faulconer, I'm out of time, but one comment about Dr. Lunine's comments. There's a big radiation belt between Earth and Mars. It's called the Van Allen radiation belt. No human being has ever

gone through that intense radiation. So it sounds like Mars has something like we've experienced in the Space Station and radiation that we kind of take for granted because we've been so short in terms of our time on the Moon or in the Space Station compared to a trip right now to Mars with our current propulsion systems.

Thank you, Madam Chairman. I yield back. Go Navy, beat Army.

Chairwoman HORN. Thank you very much, Mr. Olson.

The Chair now recognizes Mr. Perlmutter for 5 minutes.

Mr. PERLMUTTER. Thanks. And thank you to the panel for being here today.

And, Dr. Lunine, I want to start with your last comments about thinking that we would be moving on to Mars at some point after we had traveled to the Moon. And that's really been my driving motivation here is, OK, it's about time, it's about time we move on and we get—and I've been agnostic as to whether we go straight to Mars, we go to the Moon as a waystation, but ultimately to get to Mars. And Mr. Gerstenmaier has heard me say this a dozen times or more now, which is—and we heard from some NASA experts that 2033 was a feasible timeframe when the orbits, so the orbital mechanics, it's not just schedule-driven, but it's actually driven by, you know, the orbits of these two planets, that that's a shorter travel, you know, shorter journey than before.

So as I listen to you all, I mean there's the rocket science and how we deal with the potential radiation issues and our astronauts' health, and I'm convinced that we have the ability and the technology and the scientists who can work on that; the doctors. So we need from you, if I were to get the money, OK, and I've said this before, it's a chicken and egg, if you were assured that you had unlimited funds to get to Mars by 2033, Dr. Lunine, could we do it? We heard from NASA earlier, like 2 years ago, that we could do it.

Dr. LUNINE. So I would have——

Mr. PERLMUTTER. Not 2.5 percent, not a cadence of 4.4, but——

Dr. LUNINE. No, I——

Mr. PERLMUTTER [continuing]. Maybe 2.4 or 2.2.

Dr. LUNINE. I understand. So I don't—you know, in all honesty, Congressman, I don't know what infinite resources actually mean. I will say——

Mr. PERLMUTTER. OK. I'll give you an example. Do you know how much we came up for the banks over a weekend?

Dr. LUNINE. No, I don't.

Mr. PERLMUTTER. $800 billion.

Dr. LUNINE. $800 billion. So——

Mr. PERLMUTTER. OK? Now, they paid it back——

Dr. LUNINE. Yes, that's right.

Mr. PERLMUTTER [continuing]. With 15 percent interest.

Dr. LUNINE. Right. So let me answer the question, and then maybe yield to my colleagues at NASA, if you wish. So in our report, we estimated the cost of getting humans to Mars as being essentially in that range. Now, in the schedule-driven version of our study where you're driven by a schedule, we found that you could get to Mars in the mid-2030s, but bear in mind that report was written in 2014, so that's already 5 years ago. Our estimates based on the Design Reference Missions, and so on, require that the

human spaceflight part of the NASA budget grow each year by about 4 times the inflation rate through 2030 in order to make that happen. But again, that was 2014, and I think I'd like to, if you wish, yield to my NASA colleagues now.

Mr. PERLMUTTER. Certainly. And I do want to welcome the two Coloradans to the panel: Mr. Sirangelo and Mr. Faulconer. Thank you.

Mr. SIRANGELO. Thank you, sir. I can't answer the 2033 question as you asked, but what I can answer is to say that this expediting the plan to the Moon, expediting our knowledge of how to move in space, how to live in space, how to work in space, how to build the systems that allow us to do these things, is only going to have a positive effect on our ability to get to Mars. So I think the two are linked.

Mr. PERLMUTTER. So let's talk about the politics of this for a second. And, Dr. Sanders, I appreciate you talking about you can't have too aggressive a schedule because the potential risk is a problem. But on the other hand, if we don't have a schedule, then you've got a problem up here. OK, this isn't so much the engineering feats that you all will have to accomplish, there has to be a financing sort of goal here, otherwise you'll never see it. So it is a chicken and egg. We've got to have something that says we can do this by this date if you give us this kind of money. And that's what I need. And Mr. Gerstenmaier spends about 2 weeks every month here testifying before this Committee, so he's heard this before. And it may be completely a Pollyannaish vision that I have, but I have, Dr. Lunine, that drive that you talked about from being a kid who wants to see us get to Mars, with the Moon being maybe the stepping stone, but the goal being Mars. And I'm saying that to my friend, Mr. Sirangelo, too.

With that, I yield back to The Chair.

Chairwoman HORN. Thank you. Thank you, Mr. Perlmutter. And thank you for your clear intention. I think we always know we're going to see one of the bumper stickers every time.

The Chair now recognizes Mr. Waltz for 5 minutes.

Mr. WALTZ. Thank you, Madam Chairwoman.

Thank you so much for coming today, and I'm really thrilled to be on this Committee. My district runs just north of Cape Canaveral, with Embry-Riddle University front and center there. The world's leading aeronautical university. And the Chairwoman and I are, I think, a handful of Members that are on both Armed Services and the Space Committee. So we're seeing both sides of what we're calling the 21st century space race.

The Acting Secretary of Defense likes to use the term new space to describe the expanding role of the commercial space industry and developing defense space technology and also commercial space technology. Can you discuss the critical importance of commercial space to NASA's deep space missions, the lessons you're learning from their launches from Cape Canaveral, we're expecting launches every week by 2021, and then, you know, as you're in phase, I guess, phase alpha, or phase A of your planning for the Moon landing, how are you engaging commercial space in the private sector in your planning sessions? We'll start with Mr. Gerstenmaier.

Mr. GERSTENMAIER. Again, I think we're at a very unique time where commercial space could really contribute in a major way to what we're doing. And I think that's really important. And I don't consider it new space and old space, I consider it space.

We learn a lot from the new participants in the space program. They don't have some of the concerns and some of the slowness that we have. We can learn how to move fast again, but then we also have some experience and some things that actually help them too. So this working together actually makes us much stronger working together and moving forward. We're very actively engaged with them. We're asking them for ideas on how to move forward. Where NASA would have probably done the total design before, we're now actually involving them in the design process. So we can get their good ideas to see what they've learned, to see how we can keep manufacturing low, and how we can meet the timeframes moving forward.

So I see this as a tremendously positive time. I think we might be in a unique opportunity where we can really team together, work together as a team and achieve these aggressive goals toward 2024 and on to Mars.

Mr. WALTZ. So the various companies, which we probably don't need to go through, but they're being actively engaged now, so that the budget and the plan that will come to the Committee in the next, I hope in the next few weeks will have commercial private-sector participation built into those planning procedures?

Mr. SIRANGELO. Yes, sir. And I'll go a step further. As Bill mentioned, the teaming, you're seeing the teaming here evidence in front of you, sir. I've spent my career in the commercial space industry, was one of the founders of the Commercial Spaceflight Federation, and chaired it for several years. So the idea of NASA creating the team not only outside, but inside, is a very useful thing for what we're trying to accomplish.

One of the reasons for the delay in the planning process here is that we did reach out to industry, and have had dozens of meetings at the Space Symposium and since then, with industry throughout the United States, throughout the different types of companies in the industry to make sure we did hear these voices, make sure we did understand what—how they could be part of this. And I think the plan you will see will show a balance of using traditional space, NASA centers, NASA space, along with a very significant contribution from the commercial industry.

Mr. WALTZ. Thank you. Earlier this year, the Defense Intelligence Agency released a report about Russia and China's activities in space, and long story short, Russia and China both explicitly intend to eclipse the United States in space, and they are both developing rockets comparable to SLS. From your perspective, why is it important that the U.S. have the most powerful rocket for both exploration and national security, and what do you make of the Chinese landing on the backside of the Moon, but then also the recently announced research station?

Mr. GERSTENMAIER. Again, I think having a heavy lift launch capability is critical to us to be able to get large masses to the vicinity of the Moon. That's really important. And I think this is where this commercial and government approach works well together.

The SLS can launch as a backbone and carry the pieces that have to be launched as one combined package in one shot. Then you can use the commercial industry to launch multiple other small pieces to aggregate around the Moon. So I think that's critical to us keeping forward and being a leader in space, to continue to push those things that don't yet have a real opportunity yet for big revenue. That's the appropriate role for government. Mark, anything?

Mr. SIRANGELO. I agree with that, but I would—I also take one step forward. You know from your time being a Green Beret that sometimes you need to stand up and take a stand, and I think in this instance what we're doing is saying that we're not going to let that happen. It is part of America's DNA as we talk about it be part of the leadership of this industry, and I think what we are doing here and the whole aspect of our plan is to be able to step up and ensure that we keep ourselves at the forefront of that.

Mr. WALTZ. Absolutely. Thank you, Madam Chairwoman.

Chairwoman HORN. Thank you, Mr. Waltz.

And thank you to all the witnesses. But before we adjourn, the Chair and Ranking Member have a few additional questions, so if you'll indulge us for a few more moments.

So I think we've raised some really important issues, and that was the critical component of having this hearing today, even without the full plan.

So directing these first couple of questions for Mr. Sirangelo and Mr. Gerstenmaier, so you've said that NASA has come up with preliminary cost estimates for the moving of the 2024 program, but right now that those cost estimates are under review by NASA CFO (Chief Financial Officer), and then OMB. So we've got some more steps to go. So I can understand, of course, having the CFO review it, but I'm curious about what role—what OMB's review will entail. Do they have in-house expertise in engineering or program management, and program management that's going to be really sufficient enough to credibly modify NASA's cost estimates, because you're clearly the ones with the expertise on what it's going to take to do this, and what it will take to carry out your mission.

So what is OMB's role in this, and what resources do they have?

Mr. SIRANGELO. OMB's role is as a statutory role, ma'am, and from our perspective it's a—we have to go through this. It's not just a technical plan that has to be done in order for this to be communicated and brought to the Committee in the proper manner, we have to have an entire plan put together that includes not only the funding, but how do we get it, where does it come from, and how does it fit into the Administration's view.

Chairwoman HORN. Yes, I appreciate that and know that role. I think the basic concern here, as it's pretty clear that regardless of party, we are supportive of NASA, we want to see this succeed, but we've seen in the past what happens when we don't have all the pieces of the puzzle together. And so I think the basic concern is whether NASA is going to be allowed to ask for the budget it needs, that—going back to Mr. Lucas' point about sufficient funding, the budget it needs to do these lunar missions, or is it going to be a lesser amount, because—that OMB would find acceptable, because, you know, OMB doesn't have accountability if these things succeed or fail, they have a different role, but we know if it fails,

the blame is going to fall to NASA. And that goes back to the need for the plan and the sufficient budget. So if the mission fails, it's NASA that's going to shoulder that burden, and I think all of us lose in the end for so many reasons that we've discussed.

And so, Dr. Sanders, I want to turn to you for a moment and ask you to talk for a moment about any risks related to a hard goal that is insufficiently funding—insufficiently funded.

Dr. SANDERS. It's a huge risk because it puts NASA in the position of having to try to achieve something that's not really achievable. And NASA is full of people who are can-do people. I mean they're enthusiastic, they're technically capable, they will work their hearts out to try and make it work, and—but then it's easy—easy, it's possible then to start to rationalize that, OK, well, we can take this shortcut because it's important and we're going to get there, we'll do it, we're going to—we'll make it work, whether it's actually feasible to do it. So I think there's a huge risk if you don't get the adequate resources to go with the schedule. You know, it's always a three-legged stool. You have the cost, schedule, performance. You fix two of them, the other one, that's where it goes.

Chairwoman HORN. Thank you very much. And I think that goes to the underlying need to see a more detailed plan so that we can ensure the next steps and there's sufficient funding, because I think many points, so we have to balance risk; what is the right risk, and ensure that schedule pressure doesn't overcome that, and that there's sufficient funding to do what NASA is being asked to do.

And with that, I will yield to Ranking Member Babin.

Mr. BABIN. Thank you, Madam Chair.

Just a couple more questions here. I wanted to ask about the ISS, Mr. Gerstenmaier. It's one of our Nation's greatest technological international achievements. Currently, the U.S. and its partners are planning to operate it through 2024. According to the National Research Council's Pathways report from 2014, if NASA maintains their presence on the ISS past 2024 without significant increases to NASA's overall budget, it will lack the resources to fund the development of systems that will push human presence beyond low-Earth orbit until late in the next decade. This would leave the Orion vehicle without a clearly defined mission, yet abandoning the ISS could mean ceding global leadership in low-Earth orbit to other nations and our competitors.

How do we solve this dilemma? If additional funding is the answer, where do you propose that we get this additional funding? Mr. Gerstenmaier.

Mr. GERSTENMAIER. I think our proposal is to do both: To continue to use the ISS because it's a critical testbed to test the technology that's going to be needed going forward. For example, the carbon dioxide scrubbing system that's going to be flown on the Orion capsule, it's actually been tested onboard the International Space Station. So there's a synergy between Space Station and the exploration.

I think a lot of times we see this as an either/or trade. I really see it as an and. We need to go look at the needs for Station and the budget required for Station. We can gain some efficiencies potentially in ops. and maintenance a little bit, reduce some of those

costs, but I think ultimately we need to be in low-Earth orbit at the same time we're moving out to deep space to test technologies. Space Station is a good testbed to do that. We need to utilize Station as long as it's viable from a technical standpoint, and it's a piece of exploration. It is truly the first step in exploration. Granted, if a couple of crew members go almost a year in space, that's going to give us tremendous insight into the health mitigations that are required for crews when they go to Mars and other destinations. Station is paying real benefits today for exploration that if you remove Space Station, you actually cripple Space Station, you slow down our goals to get to the Moon, you slow down our activities to move to—on to Mars.

So we need to use Station today in an effective manner. We need to figure out a way to fund both. It will not be easy for you or for us to find that funding. We'll figure out a way to do it.

Mr. BABIN. OK.

Mr. GERSTENMAIER. It's necessary for us in the future.

Mr. BABIN. All right, thank you. Then another one to you as well. Will NASA develop spacesuits for surface operations and update NASA's aging extravehicular mobility units (EMUs)? EMUs were designed over 40 years ago. They were designed to fit astronauts who made up the Astronaut Corps at that time. Since then the Astronaut Corps has diversified, requiring a broader range of sizes. If we are to extend ISS, what are your plans for EMUs?

Mr. GERSTENMAIER. Yes, we're working on both. The answer, basically, is yes to both. We're working on a new spacesuit for the Space Station. The goal was to demonstrate, I think in 2024, and that suit, the life support system on the back part of the suit that provides oxygen and CO_2 scrubbing for the crew members, also a humidity control and temperature control. That's common between an orbit spacesuit, and it's common to potentially a spacesuit used on the surface of the Moon. So there's applications there. But our intent is to develop the suits necessary for both cases. And the Johnson Space Center in-house team is working on that spacesuit development today. They've actually been in NBL (Neutral Buoyancy Laboratory) doing some activities with that suit.

Mr. BABIN. OK. All right, great. Thank you.

And last, the European Service Module is currently manifested through Exploration Mission-2. After that, should NASA plan on using a European service module, or should it seek other more capable alternatives that may facilitate a broader architecture? Mr. Gerstenmaier.

Mr. GERSTENMAIER. Again, I think there's real advantages of—to us working with our partners in space, and we can selectively choose where we put those partners in the critical path. We have put the European Space Agency in the critical path for the Orion service module. That's a propellant system that maneuvers Orion around in space. They've delivered on their promises. They were a little late with the first module——

Mr. BABIN. Right.

Mr. GERSTENMAIER [continuing]. They're doing well on the second module, and they're actually starting to procure and acquire hardware for the third service module. So——

Mr. BABIN. OK.

Mr. GERSTENMAIER [continuing]. But again, I think if they continue to deliver, they're a strong partner, they can work with us, they help achieve our goals in a more effective manner and build the international strength that makes these future activities possible.

Mr. BABIN. Anybody else like to add to that? No. Nobody wants to chomp on that one. OK, thank you very much, Madam Chair.

Chairwoman HORN. Thank you very much, Ranking Member Babin. I want to once again thank all the witnesses for being here, before we close.

These are critical conversations that we need to have, and information that we need to obtain. And I think it's safe to say that Mr. Gerstenmaier, we'll probably see you here again, and many of you, so hopefully, you like seeing our faces. So thank you all for being here.

And need to say that the record will remain open for 2 weeks for any Members who wish to add statements to the record or additional questions, and the questions taken for the record. We'll look forward to getting those from you. And the witnesses are now excused, and we're adjourned.

[Whereupon, at 4:26 p.m., the Subcommittee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Mr. William H. Gerstenmaier and Mr. Mark Sirangelo

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE AND AERONAUTICS

Keeping Our Sights on Mars: A Review of NASA's Deep Space Exploration Programs and Lunar Proposal

Questions for the Record to:

Mr. Gerstenmaier and Mr. Sirangelo (NASA)

Submitted by Chairwoman Horn

Question 1-1a:

Mr. Gerstenmaier noted on April 30 at the joint Space Studies Board/Aeronautics and Space Engineering Board meeting at the National Academies that the proposed 2024 Moon landing would be "minimalist." How long will the first mission on the lunar surface last? What activities will the astronauts conduct?

Could these activities be performed by robotic missions?

Answer 1-1a:

NASA anticipates that Artemis 3 (the crewed landing, in 2024) would be a shorter lunar surface sortie than future missions, which are planned to last about seven days. The concept of operations for surface activities for the Artemis 3 crew is under review.

Question 1b:

Is an earlier mission going to pre-place cargo on the surface in preparation for the human landing, and if so, are precision landing capabilities sufficient to land astronauts nearby?

Answer 1b:

Logistics for Artemis 3 will rendezvous and dock at the Gateway and prior to the astronauts descending to the surface, the logistics will be transferred into the Human Landing System. For the surface landings, NASA is advancing precision landing capabilities that can be applied to lunar missions. This includes:

- Navigation Doppler Lidar, which provides direct velocity and ranging measurements using Doppler-based techniques;

- Hazard Detection Lidar, capable of generating a real-time, 3-D terrain map within a 50-meter radius of the landing target, at a sufficient range to allow for safe landing site determination;
- Algorithms for performing guidance and navigation, including Terrain Relative Navigation (TRN) and Hazard Detection; and
- Advanced computing capabilities, via a high performance space computing-based platform with a path to spaceflight, capable of supporting processing-intensive algorithms for navigation and image processing.

NASA is also considering whether the Science Mission Directorate's Commercial Lunar Payload Services (CLPS) contract vehicle could be used to deploy small robotic landers to either scout potential landing sites or pre-position other equipment on the lunar surface.

Question 1c:

When would the second mission occur, and how often would NASA anticipate subsequent missions occurring?

Answer 1c:

Notionally, Artemis 4 would be launched in late 2025, and further missions would take place at approximately yearly intervals.

Question 2:

Can you explain in clear terms what new risks, if any, NASA is proposing that the U.S. Government and the American people accept in carrying out the 2024 accelerated Moon landing? What, specifically, would NASA do to drive down that additional risk to the lowest possible level?

Answer 2:

The acceleration of the crewed Moon landing does not represent a fundamentally new program, but a faster path to achieve NASA's existing objectives. While recognizing the technical risk involved with this acceleration, the Agency has the capability to retire or manage that risk, given the appropriate resources.

Question 3:

Will the NextSTEP-2 Broad Agency Announcements (BAAs) for the Gateway element architecture provide "significant commercial applications beyond NASA" as stated in NASA's NextSTEP-2 document?

Answer 3:

NASA intends for the Gateway to involve commercial partners and to support their activities on and near the Moon. The first element of the Gateway – the Power and Propulsion Element (PPE) – will be provided by Maxar Technologies as a public-private partnership. The solar-electric propulsion (SEP) system used by the PPE has extensive applications for commercial satellites, enabling station keeping and on orbit transfer.

Question 3a:

What evidence will NASA require of the proposers regarding any commercial lunar market?

Answer 3a:

NASA defers to proposers regarding their wider commercial business case, but the Agency intends to utilize commercial services in support of its lunar exploration program, including commercial launch and logistics delivery services as well as Commercial Lunar Payload Services (CLPS) for the delivery of science and technology payloads to the lunar surface, and ultimately the procurement of crew transportation to the lunar surface as a commercial service. In doing so, the Agency hopes to expand the commercial market into cislunar space and onto the lunar surface.

Question 3b:

Will the government own the intellectual property associated with the systems developed under NextSTEP?

Answer 3b:

To facilitate the commercial development of critical technologies needed for human space exploration, NASA takes steps to ensure that its contractors and partners retain the maximum rights permitted by law, unless NASA has identified a specific need to obtain rights in intellectual property for NASA's own purposes. It is part of NASA's mission to "seek and encourage the fullest commercial use of space," so it is NASA's intent to ensure that its contractors and partners are able to leverage investment to advance commercial space activities.

Question 4:

What is the safety policy associated with Gateway, surface landing, and other capabilities that would be developed under the BAA, and does it apply to government astronauts?

Answer 4:

NASA has worked carefully and diligently to assure our safety requirements span all mission phases and adequately address all credible hazards, including pad emergencies, in-flight aborts and emergency landings. Deep space exploration missions hundreds of thousands of miles from Earth bring an additional set of risks beyond those associated with regular crew missions to LEO. These risks include higher spacecraft re-entry velocities, much greater radiation exposure

associated with travel through and beyond Earth's magnetic system, etc. In recognition of these and other risks associated with deep space missions, NASA has developed draft Crewed Deep Space Systems Certification Requirements and Standards for NASA Deep Space Missions (HEOMD-003). These requirements are built upon NASA's unique human spaceflight knowledge and experience. The intent of this document is to define the requirements, standards, and certification package contents that will be used to certify systems to carry NASA or NASA-sponsored crewmembers on deep space missions. The draft document has been provided to the NextSTEP-2 Appendix E awardees for their review, understanding, and comment as they mature their human lunar landing concepts. NASA plans to work closely with these vendors and other deep space exploration contractors beginning early in the design lifecycle to address their concerns and ensure their plan for meeting the deep space requirements and standards presents an acceptable level of risk to the
Agency and our astronauts.

Question 4a:

If there is an accident, will NASA have immediate access to information on hardware pedigree, certification of parts, qualification of materials, and prior testing and analyses?

Answer 4a:

Yes.

Question 5:

How is NASA prioritizing sustainability in developing the plans for a 2024 human lunar landing?

Answer 5:

For Artemis 3, the prime focus is on a crewed landing on the lunar South Pole in 2024, with future Artemis missions building up and utilizing a sustainable infrastructure around and on the Moon. Even this initial mission, however, will support the longer-term goal of sustainability in three key respects: 1) Artemis 3 will use systems developed for NASA's deep space architecture (e.g., the Space Launch System, Orion, Exploration Ground Systems, the initial Lunar Gateway, and a human landing capability); 2) the focus on near-term results is intended to promote constancy of purpose in the long run through demonstrating the feasibility and the benefits of human exploration; and 3) NASA expects that the public-private partnerships that will be used to develop human lunar lander systems will bring innovative solutions to the table that could significantly reduce the cost and increase the sustainability of subsequent surface missions.

Question 5a:

Will NASA require it in any contracts?

Answer 5a:

NASA aims to create a sustainable deep space infrastructure that will enable access to any part of the Moon as needed. To the extent that the Agency can reasonably incorporate elements supporting that goal in near-term contract mechanisms, it will do so, but the focus of Artemis 3 is effecting a crewed landing on the lunar South Pole in 2024.

Question 5b:

Which elements of the 2024 landing (e.g., the initial space suits, a small habitation module, the integrated human lander) would be sustainable or reusable?

Answer 5b:

The two elements of the Gateway that will be deployed to support the 2024 landing (the Power and Propulsion Element and Habitation and Logistics Outpost (HALO) will be fully used by subsequent missions. The specifics of the Artemis 3 surface elements, such as space suits and human landing system, will be determined as we move forward.

Question 6:

Will preparation for a lunar field station be included in NASA's amended five-year budget proposal?

Answer 6:

No, NASA's plans for lunar surface assets, such as a field station, are in development, and not specifically supported in the amended FY 2020 budget request.

Question 6a:

If yes, what exactly this lunar field station will be and what it will do? Is it envisioned to be robotic, occasionally crewed, or permanently crewed?

Answer 6a:

There are a variety of potential configurations, user communities, and purposes (e.g., scientific research, technology or resource development) for future lunar surface assets.

Question 6b:

What is the timeline for a lunar field station?

Answer 6b:

The development timeline for a lunar field station will be reflected in future budget requests.

Question 6c:

What, if any, entities other than NASA would you anticipate using the lunar field station, and would they be contributing funding to develop it?

Answer 6c:

The specifics of a lunar field station have not been determined at this time.

Question 7:

The Congressionally-directed Mars 2033 report stated that "internal NASA planning documents do not adequately justify why many of the scientific activities that may be conducted on the Gateway could not be performed using solely robotic means." To what extent has the science community determined the relative priority of carrying out science on the Gateway versus science on the International Space Station, or a free-flying spacecraft?

Answer 7:

The Gateway will fly in a different environment than does ISS (with different levels of radiation, and thermal cycling), and at different distances from potential investigation targets (e.g., Moon and Earth). Gateway will be crewed for periods of time, offering the potential for astronaut interactions with investigations (e.g., changing out samples, adjusting instruments). These physical differences between ISS and Gateway could potentially support different lines of scientific inquiry than are possible on ISS while also presenting different financial, operational, and technical constraints.

In February 2018, NASA held a Gateway Science Workshop with these primary objectives:

1. Engage the science community with respect to the scientific potential of a lunar gateway
2. Discuss potential scientific investigations leveraging the gateway
   - including the scope of possible instruments
   - using the gateway infrastructure
3. Discuss what resources the gateway would have to provide to facilitate different types of scientific investigations

There were approximately 300 attendees from government, industry, and academia with ~180 talks covering discipline-focused areas (e.g., heliophysics, Earth science, astrophysics and fundamental physics, lunar and planetary, and life sciences and space biology) as well as cross-cutting discussions on topics including, but not limited to, external instruments, telerobotics, and orbits.

Key takeaways from the science community from this workshop were:

- Gateway, in Near-Rectilinear Halo Orbit (NRHO), offers unique opportunities across all science disciplines;

- Externally mounted sample collection with controlled pointing can collect samples and provide important science about cometary material, solar composition, interstellar particles, and near Earth objects; and
- Radiation environment of the Gateway can provide important tests of the effects of radiation on biological organisms.

Input on infrastructure capabilities to perform robust science was also derived including:

- With additional transportation infrastructure (Low Lunar Orbit transfer vehicle, surface access, sample return capability) Gateway can enable additional important lunar science; and
- Science utilization extremely constrained until the presence of an external robotic arm.

Question 8:

How will NASA respond to the Aerospace Safety Advisory Panel (ASAP) recommendation that NASA "immediately" transition to new space suits for space walks outside of the International Space Station?

Answer 8:

A: NASA is developing a flexible spacesuit architecture with common core subsystems that can be modified to support the needs of specific destinations from low-Earth orbit to the lunar surface. NASA intends to demonstrate the core spacesuit technologies and subsystems applicable to both ISS-based operations and surface exploration through a series of subsystem demonstrations at ISS beginning in 2019 and culminating in delivery of a complete suit system in 2022 or 2023 for an on-orbit demonstration at ISS prior to the 2024 lunar mission.

Question 9:

Has NASA made a final decision on whether or not it will proceed with the full Green Run ahead of EM-1? If so, have any changes been made to the original testing content, and why?

Answer 9:

On July 25, 2019, NASA announced that it would conduct a "Green Run" engine test for the SLS rocket ahead of the upcoming Artemis 1 lunar mission.

During the Green Run testing, engineers will install the core stage that will send Orion to the Moon in the B-2 Test Stand at NASA's Stennis Space Center near Bay St. Louis, Mississippi for a series of tests over several months. The term "green" refers to the new hardware that will work together to power the stage, and "run" refers to operating all the components together simultaneously for the first time. Many aspects will be carried out for the first time, such as fueling and pressurizing the stage, and the test series culminates with firing up all four RS-25 engines to demonstrate that the engines, tanks, fuel lines, valves, pressurization system, and software can all perform together just as they will on launch day.

The test program for the core stage at Stennis will begin with installing the stage into the test stand. Then, engineers will turn the components on one by one through a series of initial tests and functional checks designed to identify any issues. Those tests and checks will culminate in an eight-minute-long test fire, mimicking the full duration of the stage's first flight with ignition, ascent and engine shutdown. The results of this test also will provide important data that will confirm how the system reacts as the fuel is depleted from the propellant tanks.

The SLS program is performing the stage testing with flight hardware. Once the validation of the stage is complete, the entire stage will be checked out, refurbished as needed, and then shipped to NASA's Kennedy Space Center in Florida for the Artemis 1 launch.

Question 9a:

If not, when will you make the decision?

Answer 9a:

Please see response to Question #9, above.

Question 10-10a:

The Congressionally-directed Mars 2033 report indicated that, under the previous 2028 lunar landing plan, NASA would need to begin systems development of a Mars deep space transport spacecraft in 2024 in order for it to be ready for a 2039 human mission to orbit Mars.

- What timeframe does the current lunar plan assume for a future crewed mission to the surface of Mars?

Answer 10-10a:

NASA is focused on creating a sustainable presence on the Moon as a stepping-stone for future human missions to deep space destinations, including the surface of Mars. The Agency intends that the technologies and operational techniques developed in the relatively nearby proving ground of cislunar space feed forward to Mars missions. As our near-term activities on the Moon inform our planning for Mars missions, those details will be reflected in future editions of the biennial National Space Exploration Campaign report to Congress, the first edition of which was submitted in September 2018.

Question 10b:

When would NASA plan to initiate development of a Mars deep space transport?

Answer 10b:

Please see response to Question #10a, above.

Question 11:

How would Entry, Descent, and Landing (EDL) technology developed for the lunar surface be useful toward a landing of humans on Mars?

Answer 11:

Given that Mars has an atmosphere, there are substantial technical differences between the entry, descent, and landing, and ascent environments of Mars and the Moon. However, precision landing technologies used to safely land on the lunar surface, will also improve landing accuracy on Mars. These technologies were described in greater depth in the response to Question #1b, but include Navigation Doppler Lidar, Hazard Detection Lidar and Terrain Relative Navigation, which will have its first infusion on the Mars 2020 mission. Techniques for integrated guidance, navigation, and control during powered landing can be leveraged from the Moon, for Mars. NASA is also starting to gather data to better model the interactions between lunar landers and the lunar surface. Although some of the physics are different, the modeling methods developed for lunar vehicles can be modified to apply to Mars landings. NASA also envisions that technologies associated with a lunar ascent vehicle could be applicable to a future Mars ascent vehicle. While a nominal Artemis mission would involve the lunar ascent vehicle rendezvousing with the transfer vehicle for a return to the Gateway, the ascent vehicle will have an abort capability that would enable it to fly directly to the Gateway without this rendezvous.

NASA is also developing the Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID) as an atmospheric entry system with its first applications for returning rocket stages and cargo to Earth. NASA expects to demonstrate this system in partnership with United Launch Alliance in 2022, proving the technology for both Earth return of payloads as well as for future Mars entry of large mass.

Question 11a:

What further development work will need to be done between the lunar landing effort and a Mars landing effort?

Answer 11a:

Among the most important capabilities NASA would develop for a Mars landing mission would be those associated with transit (both the physical vehicle and the propulsion system); Mars atmospheric entry and descent vehicle (which could rely on technologies such as a hypersonic inflatable decelerator and/or supersonic retropropulsion as well as integrated guidance, navigation and control); Mars ascent vehicle (which could be an evolution of the lunar ascent module); surface suits (which would be informed by the Agency's lunar surface suit experiment, though the hardware would have to be optimized for the Martian surface environment); and surface power systems (which could be an evolution of future lunar surface power systems). The experience with lunar *in situ* resource utilization would inform plans to conduct ISRU activities on the surface of Mars, as well.

Question 11b:

When does NASA plan to initiate Mars-specific EDL work for a human landing on Mars?

Answer 11b:

Please see response above to Question #10a.

Question 12:

The recent National Academies consensus study report, *A Midterm Assessment of Implementation of the Decadal Survey on Life and Physical Sciences Research at NASA* recommended that NASA adopt a "cautious approach" when shifting and focusing the NASA research portfolio toward more exploration-focused research, because basic research can have major impacts, sometimes unexpected ones, in the long term. How is NASA responding to this recommendation?

Answer 12:

NASA agrees with the Academies' view of the value of basic research; we are striving to achieve balance between basic research, exploration-focused research, and technology development. The Space Life and Physical Sciences Research and Applications Division is conducting basic research in ground laboratories, in drop towers, in parabolic and suborbital flight, and in low Earth Orbit (e.g., on ISS, X37B, and the Russian BION M2). The Cold Atom Laboratory on ISS is an excellent example of a facility that supports SLPSRA basic research. In addition to the non-NASA research being conducted in the ISS National Laboratory, the ISS is also conducting basic research such as the externally-mounted Alpha Magnetic Spectrometer. It is important to maintain a balanced research portfolio, and to ensure that the Agency uses the unique capabilities of ISS to support its deep space exploration efforts, as well as conduct basic research.

Question 13:

What type of workforce skills do you believe will be essential for a lunar program, and a lunar program that would be done on a rapid timescale?

Answer 13:

NASA and its industry partners have all of the workforce skills required for the lunar program from development through operations, even with an accelerated timescale.

Question 13a:

How would you anticipate acquiring and retaining those workforce skills?

Answer 13a:

Please see response to Question #13, above.

Question 13b:

What, if any, challenges or changes might be involved in meeting workforce requirements and how might NASA address them?

Answer 13b:

Please see response to Question #13, above.

Question 14:

Mr. Gerstenmaier testified that NASA would look at "a mixture of approaches depending on the hardware and the systems that we put together" for acquisition of the 2024 lander system. What will be NASA's acquisition strategy for the Gateway and a lunar surface program?

Answer 14:

NASA employs several kinds of mechanisms to work with the commercial sector to advance U.S. space capabilities and to purchase use of such capabilities to meet NASA's requirements. These mechanisms may include – but are not limited to – contracts resulting from competitive procurements to fulfill specific Agency requirements, as well as contracts resulting from the use of competitive acquisition for research and development through the Broad Agency Announcement (BAA) process that will advance NASA mission and program objectives and mature commercial capabilities. These contractual instruments represent just two of the mechanisms NASA employs to encourage commercial innovation while obtaining research and development of technologies that NASA may later acquire use of or ownership to meet mission needs.

The following represents a top-level snapshot summary of recent and near-term acquisition activities for Gateway, Human Landing System, and supporting systems:

- Integrated Human Landing System
  - 11 companies were awarded contracts under NextSTEP BAA Appendix E – Descent Element, Transfer Element, and Refueling for studies and prototypes
  - Multiple industry systems will be developed to support a 2024 lunar landing demonstration mission via contracts to be awarded under NextSTEP BAA Appendix Human Landing Systems

- Gateway
  - May 20, 2019 – NASA released the Request for Proposals (RFP) Synopsis for Gateway Logistics Services May 23, 2019
  - NASA awarded the Power and Propulsion Element (PPE) to Maxar Technologies

  - The Gateway platform will include a minimal pressurized habitation module with environmental control and life support systems to house astronauts during lunar missions. In order to meet the Gateway Program's schedule and support the Vice President's 2024 human lunar landing mandate, NASA determined it was necessary to continue to work with Northrop Grumman Innovation Systems for these highly specialized services.

- Refueling Element
  - The study phase for the Refueling Elements is already underway as part of contracts awarded under NextSTEP BAA Appendix E

In the case of the Gateway, on May 23, 2019, Maxar Technologies was awarded a firm-fixed price contract to partner with NASA to develop and demonstrate the PPE element. The PPE BAA, released on September 6, 2018, provided a minimal set of NASA unique requirements allowing industry room to innovate and add their own objectives. The firm-fixed price award includes an indefinite-delivery/indefinite-quantity portion of up to $12 million total for additional identified analyses and risk reduction activities. Maxar will own and operate the PPE during development, launch, and flight demonstration. The flight demonstration will last as long as one year, after which NASA will have the option to acquire the residual post-demonstration in-flight asset for use as the first element of the Gateway.

Question 14a:

What are the criteria for decisions on whether or not systems will be procured through firm-fixed-price, cost-plus, or other acquisition approaches?

Answer 14a:

The particular approaches to be employed in future acquisitions will depend on a variety of factors designed to match the unique circumstances of the procurement with the appropriate acquisition mechanism as well as applicable lessons learned from previous efforts.

Question 15:

Mr. Gerstenmaier testified that NASA does not have a space suit that is "appropriate for the activity for the moon today," but that NASA has "portions of the suit that are sufficient." What portions of the suit does NASA already have and what portions of a suit needed for 2024 still need to be acquired and/or developed?

Answer 15:

NASA is developing a flexible spacesuit architecture with common core subsystems that can be modified to support the needs of specifics destinations from low-Earth orbit to the lunar surface. The Agency plans to conduct a suit demonstration utilizing the new spacesuit architecture optimized for LEO on the ISS in 2022 or 2023 to validate the performance of the exploration Portable Life Support System (PLSS) and rear-entry upper torso assembly.

For the lunar surface, NASA will need a high mobility lower torso assembly, outer protective garments optimized for lunar dust and thermal environments, and as well as some avionics component swaps in the PLSS for lunar environment compatibility.

Question 15a:

How will NASA acquire (e.g., existing contracts, in-house development, or new acquisitions) any portions of the suit that are needed and when?

Answer 15a:

NASA plans to formulate an acquisition strategy for the lunar suits in the months ahead. The ISS demonstration suit is being assembled in-house with individual components acquired from multiple vendors across the country.

Question 15b:

If decisions on suit acquisition have not been made yet, when will they be made?

Answer 15b:

Please see response to Question #15a, above.

Question 16:

Mr. Gerstenmaier testified that NASA is taking the hardware they have already built and has "figured out how to implement that hardware to achieve the lunar goal." What existing hardware, specifically, is NASA using to achieve the lunar goal and under which programs has that hardware been developed?

Answer 16:

NASA's human lunar exploration effort will employ the Space Launch System, Orion crew vehicle, and Exploration Ground Systems funded under Exploration Systems Development. The high power, high throughput SEP spacecraft work begun under the cancelled Asteroid Redirect Mission was leveraged to jump start the Gateway PPE activities. NASA recently awarded a contract to Maxar Technologies to partner with NASA to develop and demonstrate PPE, the first element of the Gateway. Previous investments in spacesuit technology funded under the Game Changing Development Program, Small Business Innovative Research Program, and Advanced Exploration Systems are included in the flexible spacesuit architecture. Beyond this, it is important to note that the lunar program will employ resources developed across the Agency, including the Human Exploration and Operations, Science, and Space Technology mission directorates, to attain its lunar goals.

Question 16a:

How much adaptation of existing hardware would NASA need to carry out in order to make it usable for a potential 2024 landing?

Answer 16a:

The Agency's existing hardware was designed and has been built for deep space exploration, including cislunar flight.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE AND AERONAUTICS

Keeping Our Sights on Mars: A Review of NASA's Deep Space Exploration Programs and Lunar Proposal

Questions for the Record to:

Mr. Gerstenmaier (NASA)

Submitted by Congressman Bera

Question 1:

Can you please share all of the studies that have been done on the economic return on investment from NASA's Apollo Program?

Answer 1:

Please see attachment, which discusses Apollo impacts and Apollo-era spinoffs.

Responses by Dr. Patricia Sanders

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE AND AERONAUTICS

Keeping Our Sights on Mars: A Review of NASA's Deep Space Exploration Programs and Lunar Proposal

Questions for the Record to:

Dr. Patricia Sanders

Submitted by Chair Horn

1. What has been the ASAP's assessment of the use of public-private partnerships with firm-fixed-price contracts, like the Commercial Crew Program, for new development efforts? How can Congress ensure the U.S. Government will have the insight and oversight necessary to ensure any lunar systems acquired under this approach are safe and follow rigorous safety practices?

The use of public-private partnerships – with or without firm-fixed-price contracts, like the Commercial Crew Program (CCP) have potential advantages, but there were important lessons learned in CCP that should be heeded. Key among these is communication and teamwork between the government and the commercial providers from the first initiation of the effort. There needs to be a clear, unambiguous and shared understanding of the requirements – especially for certification for human flight. CCP evolved to this shared understanding of responsibility and accountability for mission assurance over time, but future efforts should strive for that from the onset. Without the establishment of this true partnership approach, there is serious risk that the government's insight will be insufficient and the outcome will not meet expectations.

2. The EM-3 mission will be only the second crewed mission of SLS/Orion, and NASA testified that they plan to use it to launch humans to the Moon for the 2024 landing. Does ASAP have any concerns about using EM-3, the second crewed SLS/Orion mission, just to achieve an arbitrary 2024 deadline?

The ASAP does have concerns about the EM-3 (now called Artemis 3) mission being used to launch humans to the moon. However, if Artemis 2 is successful and test objectives are met with no substantive anomalies, the use of SLS/Orion for the 2024 landing might not be the most significant concern. While the plan is still emerging, we may have concerns with the rest of the landing system. Requirements for the development and human rating of that system have begun, but are not yet complete, although study efforts with several potential providers are underway and will include some prototype hardware. The ASAP will be assessing the plans but would like to see them include key risk reduction aspects such as (1) carrying two providers

through to flight; (2) an uncrewed flight test prior to the first use with crew; and (3) substantive government involvement with the development as discussed above.

3. Could you please explain why the ASAP continues to deem the Green Run test "critical?" What are the key systems being tested in the Green Run, and what would be the risk were it not fully performed?

A green run is the first time the engines are assembled into a single configuration with the core stage and fired at essentially full power to test the compatibility and functionality of the system to ensure a safe and viable design. The SLS Green Run will essentially fly the core stage in place on the test stand through a nominal launch and ascent. This involves several firsts, including first cold flows, the first full tanking, and the first hot fire of the four RS-25 engines integrated with the core stage propulsion system.

The tank pressurization system for SLS relies on engine tap off for H2 and O2. This system has been analyzed and designed based on tank transfer and fluid mechanics using NASA's best numerical simulations, but the tank size and thermodynamics make this difficult. The Green Run will allow sufficient run time at various conditions to validate the models and confirm integrated performance. The Green Run could expose design problems that are not apparent without operation. This has been the experience in previous propulsion development programs. The location at Stennis allows for better access to fix problems and exposes less flight hardware to test conditions than a short duration Flight Readiness Firing at Kennedy Space Center, and the solid boosters, launch pad and mobile launcher will not be exposed to static engine plume heating and potential damage.

The ASAP believes that there is no other test approach that will gather the critical full-scale integrated propulsion system operational data required to ensure safe operations.

4. You discussed the risk value proposition for human spaceflight in your prepared testimony, and the ASAP recently closed its longstanding recommendation with respect to Radiation Risk for Deep Space Missions. What led ASAP to close this recommendation, and how do you see the risk tolerance decision with respect to radiation concerns?

In 2014, the ASAP made the following recommendation with respect to Radiation Risk Decision on Deep Space Mission: The ASAP recommends that (1) NASA continue to seek mitigations for the radiation risk and (2) establish an appropriate milestone decision point by which to determine acceptability for this risk to inform the decision about a deep space mission. This risk choice should be made before NASA decides to go forward with the investment in a future long-term mission.

NASA concurred with the recommendation and the ASAP has regularly engaged with the Office of the Chief Health and Medical Officer (OCHMO) to discuss progress on this issue, to include consideration of the NASA plan to implement the recommendations of the Institute of

Medicine Study of 2014. It is clear that there are few options for mitigating radiation exposure during long duration space flights (e.g., travel to Mars) beyond shielding and enhanced propulsion to decrease transit times. Both are active considerations and both pose technical challenges. Meanwhile, NASA continues extensive assessments to understand the actual effects of radiation exposure on humans with the acknowledgement that the impact may not emerge until years after that exposure. NASA monitors the health status of former astronauts and also follows the development of treatments for the potential impacts, i.e., certain types of cancer, being undertaken by other organizations. Additionally, NASA looks to the implementation of authorized lifetime treatment of occupational related medical conditions for astronauts should exposure lead to radiation related malignancy or radiation related degenerative effects in later years of life.

Although the ASAP remains concerned about radiation risk, we believe that NASA is addressing the risk in a manner that allows maximum risk mitigation options. We will continue to monitor this issue along with the many hazards of deep space exploration.

Responses by Dr. Jonathan Lunine

Answers by Jonathan Lunine

Q1 The following make EDL on Mars challenging relative to the Moon

Mars has an atmosphere thick enough to require which is thick enough to require a heat shield to survive hypersonic entry. The moon has none.

Mars' atmosphere is not thick enough to slow the spacecraft down sufficiently to use parachute systems without a terminal rocket descent or, for very light payloads, airbags (these aren't practical for the heavier payloads, including those with humans). Recent parachute systems have pushed the state of the art on supersonic deployment.

Mars gravity is double that of the Moon, so that a propulsive descent requires larger rocket systems and hovering to find a safe landing site is more difficult. Simply replicating systems used for rovers is not enough, as those systems landed one metric ton (MT); a human mission would require landing 40 to 80 MT. As the Pathways report states (p. 134) "Technical challenges are ranked high because the technologies needed for a Mars EDL system capable of handling very large payloads have yet to be identified. The capability gap is ranked high because the payload capacity of the necessary EDL systems are currently far beyond the capability of existing EDL systems."

Q2. Decision rules quoted from the "Pathways to Exploration Report p. 39"

Once on a pathway, if and when technical, cost, or schedule problems arise, they should be addressed by the administration, NASA, and Congress by applying the following Decision Rules:

A. If the appropriated funding level and projected 5-year budget projection do not permit execution of a pathway within the established schedule, then do not start down that pathway.

B. If a budget profile does not permit the chosen pathway, even if NASA is well down it, then take an "off-ramp."

C. If the U.S. human spaceflight program receives an unexpected increase in budget for human spaceflight, NASA, the administration, and Congress should not redefine the pathway such that continued budget increases would be required for the pathway's sustainable execution, but rather the increase in funds should be applied to retire rapidly significant technology risks or increase operational tempo in pursuit of the pathway's predefined technical and exploration goals.

D. Given that limitations on funding will require difficult choices in the development of major new technologies and capabilities, give priority to those that solve significant existing technological shortcomings, reduce overall program cost, allow for an acceleration of the schedule, and/or reduce developmental or operational risk.

E. If there are human spaceflight program elements, infrastructure, and organizations that no longer contribute to progress along the pathway, the human spaceflight program should divest itself of them as soon as possible.

Applying the rules to a 2024 piloted lunar landing: Assuming the Moon to be an intermediate stepping stone rather than the final destination, Rules A-C are strictly not applicable, as they apply to the entire set of stepping stones to Mars as a program. Such a program is not in place.

However, were one to apply the rules to this first stepping stone (lunar landing in 2024), one can say that if the five-year budget runout for a 2024 lunar landing program does not allow for development of key technologies that would feed-forward to Mars—because, e.g., the lunar landing is a sprint that jettisons anything not essential to the landing itself—then it doesn't contribute to a valid pathway to Mars. In that case, were Mars in fact the horizon goal, this might be an argument not to pursue the 2024 lunar landing goal, but opt instead for a stretched out schedule that puts humans on the Moon in a later year.

On the other had, should more funding become available, decision rule C would say that the lunar landing ought not to be accelerated in time, but instead the extra money ought to go to retire significant risks for the total set of stepping stones to humans on Mars. These might include making the early lunar landings more capable, and/or more robust in terms of more extensive surface exploration or a more capable gateway (or others areas that would reduce overall risk for human spaceflight in deep space relevant to the Mars goal).

As for D and E, the accelerated lunar landing program runs the risk of deferring technologies that would otherwise enable a Mars landing in favor of those that allow a 2024 date for a lunar landing (rather than a later one). This would violate decision rule D. And there might be a number of technologies for the 2024 lunar landing that, having a short lead time, represent compromises that don't feed forward to the Mars program, in direct contravention of rule E.

Q3. I do not have the expertise to answer this question, but I note that another panel member has received and answered this question. (Falconer).

Responses by Mr. Walter Faulconer
June 10, 2019

The Honorable Kendra S. Horn
Chair
Committee on Science, Space, and Technology
Subcommittee on Space and Aeronautics
2321 Rayburn House Office Building
Washington DC 20515-6301

Thank you again for the invitation and honor to participate in the May 8, 2019 hearing entitled "*Keeping Our Sights on Mars: A Review of NASA's Deep Space Exploration Program and Lunar Proposal.*"

Questions for the Record:

1. What type of workforce skills do you believe will be essential for a lunar program, and a lunar program that would be done on a rapid timescale?

- ***What, if any, challenges or changes might be involved in meeting workforce requirements and how might NASA address them?***

Response:

Skills - There is not a severe workforce issue at the engineering and technology skill level. NASA and industry have the technical and engineering skills needed for a lunar program and one done on a rapid timescale. The problem is (1) top-to-bottom leadership and (2) the experience gap in successfully stewarding large systems-of-systems efforts from development to completion.

The skills that are essential for a lunar program and a program done on schedule require the following key skills and acumen that are currently lacking at NASA, as documented by multiple GAO and IG findings of large development programs including SLS, Orion and JWST.

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LARGE SCALE PROJECT MANAGEMENT ACUMEN

Development versus Operations - Many of NASA's current leaders and engineers cut their teeth on ISS development back in the 1990s, which was done on a flat budget, the quintessential "go as you can pay" program. Additionally, many of NASA's current leaders come from the "operational spaceflight" world versus "major systems development". These are very different and require very different skills and experiences.

A good example of this situation is that the people at major U.S. airlines have the skills to fly, operate and maintain the planes and are good at what they do, but you would never want these

people to actually build the airplane. Likewise, you wouldn't want the engineers that designed, developed and tested the airplane trying to get you to your destination safely and on time. They are totally different applied skill sets.

Therefore, NASA does very well, from prior long-term requirements, at operating things, e.g. the International Space Station, the communications networks, and standard launch and range services. However, NASA for many years has struggled to effectively manage large scale new development on schedule and within cost. It stems in part from having "operators" trying to manage "development".

Smart Buyer - Many good people within NASA see the difficulty but they have become so risk adverse and bureaucratic and it becomes impossible to make the needed changes with the current leadership and structure. Therefore, the simple fix is always to outsource to the commercial industry. While a healthy partnership with industry where it makes sense is the best solution, NASA needs to retain 10-20% of project development to ensure technical and business acumen to 1) provide overall leadership, and 2) be smart buyers on behalf of the taxpayers. You don't become a smart buyer unless you have actually done it before.

Schedule Pressure is Good - We need to break that cultural schism resulting from Challenger (1986) and Columbia (2003) accidents that "schedule pressure is bad." The nature of your question regarding "a lunar program that would be done on a rapid timescale" and the setting a 5-year deadline to return to the moon is the antithesis of the flat budgets, "go as you can pay" and sliding schedule that NASA has practiced for at least the last 20 years. Consequently, NASA has become very good at not meeting schedules[1]. When a manager can always slip the schedule without accountability or consequences it reinforces the expected behavior that schedule is not important. This creates a flight development "death spiral" because as the schedule slips, the workforce loses precious skills honed by frequent flight testing and meeting schedules as was demonstrated during Mercury, Gemini and Apollo programs. The last effective flight test that NASA performed was EFT-1 back in 2014 with the first launch of Orion on a Delta-IV heavy. Orion hasn't launched since. Would you go to a surgeon that had not performed surgery for 5 years? Schedule pressure is a good tool for good managers who know how to use it. Schedule pressure is bad for bad managers.

NASA had many exceptional project managers during Apollo but one that stood out was Bill Tindall. In 1966, as the American space program was working furiously towards a moon landing, Bill Tindall, an expert on orbital mechanics, was sent by NASA to MIT to oversee the development of software for the spacecraft guidance systems. Tindall found a lot of brilliant people at MIT working in the development program that was behind schedule, was failing to meet its requirements, and threatened to become, in his words, "the most pacing item for the Apollo flights." He dove into the task of refashioning every aspect of the software development process, writing a series of frank memos that entered NASA lore under the name "Tindallgrams" that continued as he moved on to lead the planning of all "mission techniques" for Apollo.

[1] This statement is of course a globalization. Generally, NASA small-medium sized missions in SMD tend to do very well with their schedule management given: (1) schedule pressure (meeting planetary launch windows), (2) the development cycle is shorter, e.g. 5 years, and (3) these programs have adequate reserves planned and protected from the beginning.

Flight Director Gene Kranz said of Tindall "if there should have been a lunar plaque left on the Moon from somebody in Mission Control or Flight Control - it should have been for Bill Tindall. Tindall was the guy who put all the pieces together, and all we did is execute them." [2]

ENTERPRISE SYSTEMS ENGINEERING AND INTEGRATION (SE&I)

While NASA does a good job of Systems Engineering and Integration (SE&I) on most individual projects it currently lacks the robust enterprise level systems engineering and integration. This is due primarily to the infrequency of such developments, which prevents sustainment of a strong pipeline of systems engineering talent. Such talent is required for formation and execution of an integrated campaign including SLS, Orion, a Gateway, lunar landers, surface development, Mars preparation, etc. This is evident by continued system disconnects between SLS, Orion and Ground Systems working to sub-optimal requirements with a relatively poor understanding of key driving requirements and outcomes (e.g. what is to be accomplished on and around the moon?). A good example of this situation is after the announcement of returning to the Moon in 2024 a meeting of the NASA lunar lander team immediately focused on "who" was going to do what without even understanding the basic level zero requirements.

During the Apollo program it was recognized that NASA did not have the enterprise level SE&I capability to get us to the moon which predicated bringing on Bellcom to run the SE&I for the moon program. The Exploration program of today is even more complex than during Apollo with not only NASA centers, but commercial industry, international partners and other stakeholders along with more restrictive budgets and oversight from Congress. Because of the lack of enterprise level SE&I, NASA continues to make suboptimal system decisions which forces other follow-on suboptimal decisions. The correct way to design an exploration program is to begin with the end goal first. If the end goal is humans on Mars, then the architecture needs to define what is required and then work backward defining what is needed to be done on the moon to retire risk and enable Mars exploration. NASA does not do that but rather focuses on individual element development, e.g. SLS, Orion, Gateway without consideration of the overall architecture. Therefore, we end up, for example, with a service module for Orion that is suboptimal and under performs for the current requirements. That suboptimal decision then forces a Gateway into a higher than desirable orbit for lunar exploration. That suboptimal decision then forces a lunar lander design that is no longer 2-stages like we did in Apollo but now 3-stages to be able to reach the Gateway. If we truly had robust enterprise SE&I we would already have the architecture for robust lunar exploration leading to Mars exploration along with the requirements and system trade-offs.

To the second part of your question:

- ***What, if any, challenges or changes might be involved in meeting workforce requirements and how might NASA address them?***

[2] www.wehackthemoon.com/bios/bill-tindall

Several suggestions and recommendations are provided:

"Courageous" versus "Status Quo" Leadership – The first essential requirement is what I call courageous leadership. Leadership that is willing to do what is necessary to help reinvent the organization for the current mission and help the workforce by removing barriers to success. I addressed this in my testimony and the story of Dr. Mueller.

One of my tasks for NASA is leading the NASA Leadership Development Program for the next generation project managers called Flight Project Development Program (FPDP). On May 21-22, we had our latest workshop and I had 50 participants from all of the NASA centers, representing the best and brightest of mid-level project managers. I asked them "*how many of them felt that NASA will be able to lead us back to the moon by 2024?*". Only 3 people raised their hands. I asked them why more people didn't raise their hand and the answer was that they didn't see the leadership and the program didn't seem real two months after the announcement by the Vice President. They saw the NASA Administrator making speeches, but that was it. They didn't feel anything different at their level. They didn't experience an all-hands meeting by the Center Director telling them how they will be refocusing and how the organization was changing to accomplish this new goal. They didn't experience their immediate supervisor helping them understand the new direction and sense of urgency. There was no communication at all. This is quite an indictment of the lack of top-to-bottom leadership needed.

Ability to Quickly Move and Re-Task People – NASA has many workforce restrictions placed on them by Congress restricting the ability to hire, realign, reorganize, reward, incentivize, move and fire people. To be successful in 2024 we need the right people in the right jobs. This is one reason the attention has been on more utilization of the commercial industry since they are more free to emplace, replace, empower and reward people. We need to enable NASA to provide similar rewards and incentives to better attract and develop the right workforce needed going forward. Not to mention, the timely responsiveness and flexibility needed, by management, to replace people who's skill set does not meet the needed performance requirements. Otherwise the "culture" described under the Project Manager answer will not change fast enough to support getting to the moon by 2024, 2028 or 2033.

Innovative and Accountable Acquisition – With the emphasis on using commercial industry as much as possible, NASA needs to be given special consideration for creative acquisition. For example, Space Act Agreements were used by NASA for the ISS Commercial Cargo and Commercial Crew Programs to quickly establish partnership agreements with industry. However, recently they have rejected using such streamlined acquisition approaches for the lunar lander program and Gateway elements. If we are going to get back to the moon by 2024, NASA needs to bring a full arsenal of acquisition approaches including "sole source", other transactional agreements (OTA), potential adaptive DOD acquisition models and Space Act Agreements. We don't have the time for traditional acquisition approaches.

Stable and Consistent Funding – Why do large scale developments struggle under the NASA model? You take personnel who are perhaps among the best in their field at project management and they will struggle. Why? Because with year-to-year incremental funding these large scale

programs rarely if ever have the fiscal resources when they are needed to maximize success. Program/project managers are forced into a situation where they must over promise just to "keep the program sold". It also emits the exact wrong incentive to prime contractors, who "play" the system by hiding cost risks from NASA until they are assured to come true, thus increasing their realization of fee or extending the period of performance or both. This is exactly what happened on JWST.

There is evidence that if technical progress is allowed to govern the pace of work and not budget, then the proper early investments can be made to mitigate late cycle risks. SLS's history is peppered with a host of bad choices because they did not have the resources to invest in mitigating risk – pennywise and pound foolish if indeed the program is "too big to fail".

So Congress needs to recognize that it plays a large part in NASA's poor cost and schedule performance on big programs. To fix this dynamic Congress should consider alternate funding models – either the "capital ship" approach, or multiyear appropriations. They can always hold NASA accountable every year as to how the money is spent through the annual Operating Plan process or they can legislate their own oversight/insight model through the appropriations legislation.[3]

Thank you for your thoughtful question and feel free to contact me if I can be of further service.

Sincerely,

Walt Faulconer, President
Faulconer Consulting Group, LLC

[3] Dan Dumbacher, Executive Director, American Institute of Aeronautics and Astronautics, addressed this issue well in his testimony, June 14, 2018, "NASA Cost and Schedule Overruns: Acquisitions and Program Management Challenges," Subcommittee on Space, Committee on Science, Space and Technology, United States House of Representatives.

Appendix II

Additional Material for the Record

ARTICLE SUBMITTED BY MR. WILLIAM H. GERSTENMAIER

November 2019

Apollo Impacts

NASA's Apollo Program captured the world's attention and demonstrated the power of America's vision and technology to inspire generations of great achievements, exploration, and scientific discovery. Our leadership in space continues.

Our goal 50 years ago was to land humans on the Moon and return them safely to Earth. Our goal now is to return to the Moon to stay, in a sustainable way.

The wide and deep impacts of Apollo include technology development and innovation, advances in science, as well as political, managerial and educational benefits. These benefits and NASA's ongoing work affect every aspect of our lives here on Earth.

Areas where the Apollo ripple effect is still being felt:

Complex Systems

Management of complex systems and structures was a critical legacy of Apollo. The push to the Moon helped us establish a truly national space program.

- Only the building of the Panama Canal rivaled the Apollo program's size as the largest non-military technological endeavor ever undertaken by the United States and only the Manhattan Project is comparable in a wartime setting.
- In order to execute Apollo, NASA needed to build the infrastructure – which included building four centers in the economically disadvantaged southern part of the country (Kennedy, Marshall, Stennis, and Johnson).

Technology

Apollo was a huge technological boost to the economy. Since Apollo was conducted as an open public program, largely executed by U.S. industry, the technology development was immediately incorporated into the public economy. Among many Apollo technological spinoffs:

- Helped spur the computer revolution – with the first Apollo contract being to develop the guidance computer;
- Miniaturization of technology to save space and weight;
- Cooling garments for medical, sports, and labor use;
- Improved dialysis machines based on technology for removing toxins;
- Water purification technology;
- Self-righting life rafts that have saved hundreds of sailors;
- Flame resistant textiles;
- Advanced technology for flying aircraft;
- Heat shield technology that now protects steel in buildings;
- Metallized insulation that protects homes, buildings and equipment;
- Lifesaving cardio pumps that had their origin in rocket development;
- Small rechargeable batteries now revolutionizing hearing aids;
- Rocket-powered parachutes to escape airborne mishaps;
- Personal locator beacons;
- Launch shock absorbers that now protect buildings from earthquakes;
- Improved freeze dried food and food safety practices.

Science

Apollo opened the door to the amazing science yet to be done on the Moon.

- Science from the Moon rewrote our understanding of the origin/history of the Moon and the solar system.
- Experiments placed on the Moon and samples returned from the surface have generated scientific findings ever since.
- Lunar rocks returned are nearly as old as our solar system.
- NASA also poured resources into American education during Apollo – building facilities and contributing to the development of faculty and labs at universities and colleges across the country.

People Pursuing Science, Technology, Education, and Mathematics (STEM) Careers

- The Apollo program demonstrated the strength of America's political and economic system and inspired an entire generation to pursue science and engineering careers.
- There was a threefold increase in these types of PhDs between the mid-1960s and the mid-1970s.

Public Engagement

- The inspirational nature of the program helped us see the planet in a new way.
- First Earth Day in 1970, post Apollo 8 "Earthrise" image and Moon landing.
- One-fifth of world's population at the time, 600 million, witnessed the Moon landing, a worldwide engagement that continues today on multiple social media platforms.

Apollo-Era Spinoffs

Tensile Fabrics Enhance Architecture Around the World
Spinoff 2009: https://spinoff.nasa.gov/Spinoff2009/ip_2.html

Using a remarkable fabric originally developed to protect Apollo astronauts, Birdair Inc., of Amherst, New York, has crafted highly durable, safe, environmentally friendly, and architecturally stunning tensile membrane roofs for over 900 landmark structures around the world. Travelers in airports, sports fans at stadiums, and shoppers in malls have all experienced the benefits of the Teflon-coated fiberglass fabric that has enabled Birdair to grow from a small company established in its founder's kitchen in 1955 to a multimillion-dollar specialty contractor today.

Food Safety Approach Becomes Industry Standard
Spinoff 1991: https://spinoff.nasa.gov/database/spinoffDetail.php?this=/spinoff/jsc/JSC-SO-165

As soon as NASA started planning to send people into space, it faced the problem of how and what to feed them. Johnson Space Center enlisted the aid of the Minneapolis-based Pillsbury Company to assure absolute freedom from potentially catastrophic disease-producing bacteria and toxins. Pillsbury came up with an approach that established control over the entire production process, from the raw materials to the processing environment and the people involved. Pillsbury developed the Hazard Analysis and Critical Control Point (HACCP) concept to prevent food safety problems rather than catch them after they occurred. The Federal Government now requires meat and juice producers to use HACCP programs, and all other food companies in the United States that have to register with the Food and Drug Administration, as well as foreign companies that export food to the United States, are switching to mandatory HACCP programs. Pillsbury plants still operate under HACCP.

Fly-by-Wire Systems Enable Safer, More Efficient Flight
Spinoff 2011: https://spinoff.nasa.gov/Spinoff2011/t_5.html

Using the ultra-reliable Apollo Guidance Computer that enabled the Apollo Moon missions, Dryden Flight Research Center [now Armstrong Flight Research Center] engineers, in partnership with industry leaders such as Cambridge, Massachusetts-based Draper Laboratory, demonstrated that digital computers could be used to fly aircraft. Digital fly-by-wire systems have since been incorporated into large airliners, military jets, revolutionary new aircraft, and even cars and submarines.

Polymer Fabric Protects Firefighters, Military, and Civilians
Spinoff 2008: https://spinoff.nasa.gov/Spinoff2008/ps_3.html

In 1967, NASA contracted with Celanese Corporation, of New York, to develop a line of Polybenzimidazole (PBI) textiles for use in space suits and vehicles. In 2005, the PBI fiber and polymer business was sold to PBI Performance Products Inc., of Charlotte, North Carolina, under the ownership of the InterTech Group, of North Charleston, South Carolina. PBI Performance Products now offers two distinct lines: PBI, the original heat and flame resistant fiber; and Celazole, a family of high-temperature PBI polymers available in true polymer form. PBI is now used in numerous firefighting, military, motor sports, and other applications.

Shock Absorbers Save Structures and Lives During Earthquakes
Spinoff 2015: https://spinoff.nasa.gov/Spinoff2015/ps_2.html

With NASA funding, North Tonawanda, New York-based Taylor Devices Inc. developed fluidic shock absorbers to safely remove the fuel and electrical connectors from the Apollo spacecraft during launch. The company is now employing the technology as seismic dampers to protect structures from

earthquakes. To date, 550 buildings and bridges have the dampers, and not a single one has suffered damage in the wake of an earthquake.

Freeze-Dried Food Nourishes Adventurers and the Imagination
Forthcoming, Spinoff 2020

In the early days of the space program, one problem was feeding astronauts during their time away from Earth. Food needed to be shelf-stable and long lasting, and it needed to pack small and light and be easy to prepare. Mercury astronauts complained about the bite-sized cubes, freeze-dried powders, and semi-liquids they were given. NASA funded research that improved and popularized freeze-drying, and the Ames Research Center visitor center got in touch with Boulder-based American Outdoor Products, looking for freeze-dried ice cream. The company, one of a few making freeze-dried products for consumers, developed a technique to meet the request, becoming the first to freeze-dry ice cream, which it still sells today as the popular astronaut ice cream sandwiches.

Fire-Resistant Reinforcement Makes Steel Structures Sturdier
Spinoff 2006: https://spinoff.nasa.gov/Spinoff2006/ps_3.html

Built and designed by Avco Corporation, the Apollo heat shield was coated with an ablative material whose purpose was to burn and dissipate energy. The burned material charred to form a protective coating, blocking heat. Avco subsequently contracted with Ames Research Center to develop spinoff fire-protection applications of the heat shield, such as fire-retardant paints and foams for aircraft. This led to the production of Chartek 59, made by Avco Specialty Materials (which was acquired by Textron Inc.) and marketed as the world's first intumescent epoxy. Chartek 59 expanded when exposed to heat or flames and acted as an insulating barrier. It also retained its space-age ablative properties and dissipated heat through burn-off. In 1999, Houston-based International Paint LLC acquired the Chartek brand. The company's latest product derived from the technology, Interchar, makes high-rise buildings and public structures safer. Interchar swells to provide a tough, stable insulating layer over the steel, protecting it without impacting the overall shape of the steel. Interchar provides up to four hours of fire protection and helps prevent steel structures from collapsing, giving occupants more time to evacuate.

Radiant Barrier Insulation Cuts Home Energy Bills
Spinoff 2013: https://spinoff.nasa.gov/Spinoff2013/cg_6.html

As NASA prepared to send people out on spacewalks, it needed a more powerful insulator than researchers could find. Reflective insulation existed, but in the 1960s, Marshall Space Flight Center created a "superinsulation" from layers of lightweight, metalized thin films that would become one of the Agency's most enduring spinoffs. They've been used in a host of building insulations, but RadiaSource, based in Woods Cross, Utah, uses a version that's metallized in such a way that the aluminum never oxidizes, letting the company offer a lifetime guarantee. In addition to rolls of insulation, the company offers kits for insulating garage doors and water heaters.

Reflective Coatings Protect People and Animals
Spinoff 2010: https://spinoff.nasa.gov/Spinoff2010/er_6.html

In the 1960s, Marshall Space Flight Center created a "superinsulation" from layers of lightweight, metalized thin films for use in spacesuits and spacecraft. Based on that invention, NASA engineers called upon National Metalizing Company to help create a reflective sunshield to deploy on Skylab in place of a shield that was lost during launch in 1973. Years later, a former employee for National Metalizing founded Advanced Flexible Materials (AFM) Inc., of Petaluma, California, and utilized the radiant barrier technology in the public domain to produce a variety of products such as wraps to keep

marathon finishers safe from hypothermia as well as a lining for mittens and vests. Recently, the material helped to keep manatees warm as they were lifted from the water as part of a tag-and-release program.

Temperature-Resistant Materials Enable Space-Like Cold on Earth
Spinoff 2016: https://spinoff.nasa.gov/Spinoff2016/ip_3.html

In the 1960s, Marshall Space Flight Center created a "superinsulation" from layers of lightweight, metalized thin films for use in spacesuits and spacecraft. Since the 1980s, Dunmore Corporation of Bristol, Pennsylvania, has worked with the Jet Propulsion Laboratory and other NASA centers to develop variations on the technology, helping the company establish a massive catalog. Many of its multilayer insulations were developed for NASA and are now used in building insulation, cryogenic material transport, Magnetic Resonance Imaging (MRI) machines, and particle accelerators.

Space Blanket-Inspired Cases Protect Expensive Devices
Spinoff 2016: https://spinoff.nasa.gov/Spinoff2016/cg_4.html

Smartphones, laptops, and tablets are susceptible to damage if exposed to very high or low temperatures. Inspired by the "space blankets" he used as a Boy Scout, Nick Blanton, founder of Portland, Maine-based Salt Cases Company, developed fabric cases that incorporate multi-layer metallized thin-film insulation, known as radiant barrier, created by Marshall Space Flight Center decades ago.

Hutch Snuggle Keeps Outdoor Animals Comfortable
Spinoff 2005: https://spinoff.nasa.gov/Spinoff2005/ch_7.html

In the 1960s, Marshall Space Flight Center created a "superinsulation" from layers of lightweight, metalized thin films for use in spacesuits and spacecraft. Scratch and Newton Ltd., based in Leeds, England, employs this technology to improve the lives of pet rabbits and guinea pigs with its Hutch Snuggle protective coverings. The company also uses it to insulate pet water bottles with its Bottle Snug. Scratch and Newton has sold its products around the world.

Kegsheets Keep Beer Cold
Spinoff 2018: https://spinoff.nasa.gov/Spinoff2018/cg_6.html

NASA didn't invent reflective insulation, but the Space Agency mastered it in the form of layered metalized polyester thin films first made for Marshall Space Flight Center in the mid-1960s. Known as radiant barrier technology, this durable, lightweight "superinsulation" is used in all spacecraft and spacesuits and a host of applications on Earth. JUNTO LLC, based in Boston, now uses the technology to make KegSheets, which, coupled with ice, can a keep beer keg cold all through a hot day.

Rechargeable Hearing Aid Batteries Draw from NASA Research
Spinoff 2017: https://spinoff.nasa.gov/Spinoff2017/cg_4.html

Several early NASA spacecraft, including the Apollo command module, used silver-zinc batteries. NASA spent much effort trying to develop a rechargeable silver-zinc battery, as the pairing offers a higher power-to-weight ratio than any other battery couple. Significant advances in the batteries' durability were made at Glenn Research Center, which ZPower of Camarillo, California, used as part of its starting point, undertaking years of additional development before releasing its rechargeable hearing aid batteries, the first that can last all day on a single charge.

Cooling Garments Find Medical, Athletic, and Industrial Uses
Spinoff 2017: https://spinoff.nasa.gov/Spinoff2017/hm_4.html

In the 1960s and '70s, Bill Elkins worked with engineers at NASA and the U.S. Air Force, including several at Ames Research Center, on liquid cooling garments to be worn under spacesuits and flight suits. He has spun that experience off into several companies, including Downers Grove, Illinois-based WElkins LLC. The company markets varieties of the cooling technology to prevent brain damage after heart attacks or strokes, improve sports performance, treat concussions, and keep workers from overheating under heavy protective gear.

Spacesuit Production Leads to Lighter-Than-Air Vehicles
Spinoff 2005: https://spinoff.nasa.gov/Spinoff2005/ch_1.html

Through its work with spacesuit designing, testing, and manufacturing for Johnson Space Center, beginning with the Apollo missions, ILC Dover developed skills and processes unique to the industry. The Frederica, Delaware-based company uses the same high-performance, rugged textiles, high-strength seaming technology, and test methods developed for spacesuits to make a majority of the large lighter-than-air vehicles in use around the world.

Apollo-Era Life Rafts Saved Hundreds of Sailors
Spinoff 2009: https://spinoff.nasa.gov/Spinoff2009/ps_3.html

To keep life rafts holding astronauts from capsizing in the downdraft of rescue helicopters after Apollo splashdown landings, engineers at NASA's Johnson Space Center designed and patented a self-righting life raft capable of staying upright in choppy seas and fierce winds. Givens Marine Survival Co. Inc. of Tiverton, Rhode Island, licensed this invention and manufactured the rafts under the name Givens Buoy Life Raft in a variety of sizes and models. The company no longer exists, but Givens sold several thousand of the ballasted, inflatable life rafts, which were credited with saving the lives of hundreds of sailors.

Containment System Improves Pharmaceutical Manufacturing
Spinoff 2005: https://spinoff.nasa.gov/Spinoff2005/ch_1.html

Through its work with spacesuit designing, testing, and manufacturing for Johnson Space Center, beginning with the Apollo missions, ILC Dover developed skills and processes unique to the industry. The DoverPac, a series of high-strength, flexible, transparent tubes, provides reliable containment of highly active ingredients in powder form. The heat sealing technology, the woven bladder design, and the design of the woven-mesh outer restraint are all based on work the Frederica, Delaware-based company did for NASA.

Escape Respirators Keep Civilians Safe
Spinoff 2005: https://spinoff.nasa.gov/Spinoff2005/ch_1.html

Through its work with spacesuit designing, testing, and manufacturing for Johnson Space Center, beginning with the Apollo missions, ILC Dover developed skills and processes unique to the industry, applying them to various products. The Frederica, Delaware-based company's civilian escape respirators use the same heat seals and the same quality and inspection that keep NASA's astronauts safe in space. While traditional gas masks demand multiple sizes to fit the population, require extensive training, and are not designed for children or infants, ILC's masks are easy to use and come in one size that fits anyone.

Anti-Reflective Coatings Improve Display Screens
Spinoff 1989: https://spinoff.nasa.gov/database/spinoffDetail.php?this=/spinoff//hdqs/HDQS-SO-133

In 1963, Optical Coating Laboratory Inc. (OCLI) developed HEA (for high-intensity antireflection) coating to improve visible light in the Gemini spacecraft. In the days of cathode ray tube-based televisions and computers, screen glare was a common complaint, and OCLI made a name for itself selling HEA-coated panels to manufacturers, as well as a line of retrofit products, all of which reduced screen glare. In 2014, MAC Thin Films took over the Santa Rosa, California-based operation. Today, HEA coatings improve the clarity and color fidelity of touch screens, handheld instruments, Global Positioning System (GPS) displays, medical displays, digital signage, and more.

Metal Coatings Find Thousands of Applications
Spinoff 1994: https://spinoff.nasa.gov/database/spinoffDetail.php?this=/spinoff//hdqs/HDQS-SO-85

During the Apollo Program, General Magnaplate Corporation developed process techniques for bonding dry lubricant coatings to space metals. The coatings were not susceptible to outgassing and offered enhanced surface hardness and superior resistance to corrosion and wear. This development was necessary because conventional lubrication processes were inadequate for lightweight materials used in Apollo components. General Magnaplate built on the original technology and became a leader in the development of high-performance metallurgical surface enhancement coatings. The company now has nearly two dozen coatings that have been used in virtually every NASA spacecraft and spacesuit since Apollo, as well as applications from pizza making to laser manufacturing, injection molding, heat sinks on computers, and the boring machines that dug the "chunnel" between France and England. Each of the coatings is designed to protect a specific metal or group of metals to solve problems encountered under operating conditions.

Water Treatment Systems Make a Big Splash
Spinoff 2004: https://spinoff.nasa.gov/Spinoff2004/er_1.html

In the 1960s, NASA's Manned Space Center (now known as Johnson Space Center) and the Garrett Corporation, Air Research Division, conducted a research program to develop a small, lightweight water purifier for the Apollo spacecraft that would require minimal power and would not need to be monitored around the clock by astronauts. Carefree Clearwater Ltd., of Atlanta, Georgia, obtained NASA's permission to manufacture a modified version of the space agency's patented purification technology for numerous commercial and industrial applications, including swimming pools, hot water spas, decorative fountains, ponds, manufacturing processes, and evaporative water cooling towers. The company's systems electronically release copper and silver ions into the water to destroy bacteria and algae, which are then filtered out. Unlike chlorine, the ions do not dissipate from heat and sunlight. The technology reduces the need for chlorine, cutting down on burning eyes, odor, and bleached or dry skin and hair. And the ions pose no health risks.

Space Pens Work Under Any Conditions
Spinoff 1986: https://spinoff.nasa.gov/database/spinoffDetail.php?this=/spinoff//hdqs/HDQS-SO-144

Most pens rely on gravity to draw out ink. Fisher's Space Pen was developed for the Apollo astronauts to use in a gravity-free environment. The cartridge is pressurized with nitrogen to force ink outward toward the ball point. The "thixotropic," rubber-like ink is almost solid and only liquefies with friction from the ballpoint. The pen operates at temperatures from - 30 to 250 °F, can withstand atmospheric extremes, and even writes underwater. Fisher Pen Company's 65 employees now make dozens of variations on the original AG-7 Antigravity Pen at their warehouse in Boulder City, Colorado. The pens have been used on every crewed NASA mission since their invention.

Archiving Innovations Preserve Essential Historical Records
Spinoff 2012: https://spinoff.nasa.gov/Spinoff2012/it_6.html

The Apollo 11 mission left on the Moon a silicon disc inscribed with microscopic recreations of messages from 73 countries. NanoArk Corporation of Fairport, New York, built on that NASA technology to develop a fire- and water-resistant archiving innovation that provides cost savings and security in preserving documents.

Space-Proven Medical Monitor Is Part of Total Patient Care Package
Spinoff 2006: https://spinoff.nasa.gov/Spinoff2006/hm_2.html

Spacelabs Medical, now Spacelabs Healthcare, was cofounded by Ben Ettelson and James A. Reeves in 1958 to work with NASA and the U.S. Air Force on systems to monitor the vital signs of astronauts in space. As a prime contractor to NASA for the Gemini Program, the company manufactured and delivered prototypes of miniaturized signal conditioners to measure astronauts' temperature, respiration, and cardiac activity. The company then brought that technology down to Earth to dramatically change the course of patient monitoring. Today, the company's Intesys Clinical Suite enables easy access to patient information. One component of this suite is the Vital Signs Viewer, which allows physicians to see a patient's live waveforms and other data remotely from any networked personal computer outside of a hospital. With the suite's AriaTele telemetry transmitter and Xhibit central station, patients can be monitored constantly and comprehensively.

Liquid Cooling Technology Increases Exercise Efficiency
Spinoff 2015: https://spinoff.nasa.gov/Spinoff2015/hm_3.html

To keep astronauts' airtight spacesuits from becoming hot and humid, Ames Research Center developed liquid cooling garments that were integrated into each suit's long underwear. Vasper Systems, in San Jose, California, is using the technology in its liquid-cooled compression cuffs, which help people exercise more efficiently by concentrating lactic acid in their muscles.

Gas Regulators Keep Pilots Breathing
Spinoff 2019: https://spinoff.nasa.gov/Spinoff2019/ps_2.html

Since John Glenn's first orbit in 1962, all U.S. astronauts have used a derivation of his oxygen regulator. For the original project, Cobham Mission Systems (then operating as Carleton Controls) needed to make a gas regulator smaller and lighter than ever before. Now the Orchard Park, New York-based business uses the innovative spring design it created for Johnson Space Center and its oxygen safety expertise in oxygen systems for pilots, as well as for applications like wastewater treatment and offshore drilling.

Cordless Power Tools Offer Freedom of Movement
Spinoff 1981: https://spinoff.nasa.gov/database/spinoffDetail.php?this=/spinoff//jsc/JSC-SO-105

Apollo astronauts needed a portable, self-contained drill capable of extracting core samples as much as 10 feet below the lunar surface. Black & Decker used a specially developed computer program to optimize the design of the drill's motor and insure minimal power consumption. Refinement of the original technology led to the development of a cordless miniature vacuum called the Dustbuster. It has no hose and no cord, and comes with a storage bracket that serves as a recharger. Other home-use cordless instruments based on the technology have included drills, shrub trimmers, and grass shears. The company also manufactures a number of cordless tools used in the sheet metal, automobile, and construction industries, as well as a line of cordless orthopedic instruments.

Spacesuit Techniques Improve Athletic Shoes
Spinoff 1991: https://spinoff.nasa.gov/database/spinoffDetail.php?this=/spinoff//hdqs/HDQS-SO-193

Al Gross transferred expertise obtained as an ILC Dover engineer for NASA's Apollo program to the manufacture of athletic shoes for Beaverton, Oregon-based Avia Inc. Gross substituted DuPont's Hytrel plastic for foam materials in the shoe's midsole, eliminating cushioning loss caused by body weight. An external pressurized shell from spacesuit technology was incorporated into the shoe. Stiffness and cushioning properties of the midsole were tuned by varying material thickness and styling lines. A stress-free "blow molding" process adapted from NASA spacesuit design was also utilized. The resulting compression chamber midsole performed well in tests. It allowed Avia to reconfigure for specific sports and was a "first step" toward a durable, foamless, non-fatiguing midsole.

Fire-Resistant Fabric Increases Safety
Spinoff 1982: https://spinoff.nasa.gov/database/spinoffDetail.php?this=/spinoff//jsc/JSC-SO-29

Fire hazard is greater in atmospheres containing a high concentration of oxygen under pressure, such as the Apollo capsule. NASA intensified its fire safety research after the 1967 Apollo fire. Under contract to Johnson Space Center, Monsanto Company developed a chemically treated fabric called Durette. The material was used for a wide range of applications such as sheets, attendants' uniforms in hyperbaric chambers, and crew's clothing, furniture, and interior walls in diving chambers, as well as suits for auto racers, refuelers, and crew chiefs. Durette bags filtered gases and dust from boilers and electric generators. Today, Amron International Inc. of Vista, California, a company that specializes in diving, tactical, hyperbaric, and outdoor equipment, sells Durette coveralls, pillows, mattresses, and sheets.

NASA Parachute Innovations Carry Commercial Rockets Back to Earth
Spinoff 2017: https://spinoff.nasa.gov/Spinoff2017/t_3.html

Airborne Systems Inc., whose Space and Recovery Systems branch is in Santa Ana, California, worked as a subcontractor to build the parachute system for the Orion capsule. The design is based in part on the Apollo spacecraft's parachutes but incorporates updates and improvements requested by Johnson Space Center, which managed the contract. Johnson also carried out drop tests to prove the parachutes, which Airborne Systems now sells to several commercial spacecraft companies.

Apollo 11 History Archive Helps Virtual Reality Program Come to Life
Spinoff 2018: https://spinoff.nasa.gov/Spinoff2018/cg_1.html

So much NASA data is available online that Waterford, Ireland-based Immersive VR Education was able to recreate the first Moon landing as a highly realistic and rich virtual reality experience. NASA Headquarters maintains a vast trove of images, design plans, data, and more, with the Lunar Surface Journal among its most popular records. The company's Apollo 11 VR, an app which lets users experience Apollo 11 from takeoff to the lunar surface and back to Earth reentry, has sold more than 40,000 copies.

Workout System Improves Muscle, Cardiovascular Strength
Spinoff 1993: https://spinoff.nasa.gov/database/spinoffDetail.php?this=/spinoff//hdqs/HDQS-SO-183

In the mid-sixties, Gary Graham, a Boeing designer, developed a cardiovascular conditioner for a planned U.S. Air Force orbiting laboratory. After the project was cancelled, Graham participated in space station conditioning studies for NASA's Apollo Applications (later Skylab) Program. Twenty years later, he used this expertise to develop the Shuttle 2000-1, a physical therapy and athletic development conditioner

that's still available today through Bellingham, Washington-based Shuttle Systems, along with several variations. Football teams, sports clinics, and medical rehabilitation centers have all used the machines over the years. They use both kinetic and plyometric exercises to promote cardiovascular fitness and muscular strength development.

Plasma Heating Promises Environmentally Friendly Waste Disposal
Spinoff 1994: https://spinoff.nasa.gov/database/spinoffDetail.php?this=/spinoff//arc/ARC-SO-55

The Mercury and Apollo spacecraft shields were designed to protect astronauts from temperatures well over 2,000 degrees Fahrenheit when re-entering the Earth's atmosphere. It was necessary to test and verify the heat shield materials before spaceflight. NASA decided to use plasma heating as a heat source, a technique that involves passing a strong electric current through a rarefied gas to create a plasma that produces an intensely hot flame. Although NASA did not invent the concept, its work expanded the market for commercial plasma heating systems. A member of the team that developed the Reentry Heating Simulator at Ames Research Center, Salvador Camacho, founded Plasma Technology Corporation, believing the technology had applications in environmentally friendly waste disposal. The company no longer exists, but the technology does. In 2014, Columbia Ridge Landfill in Arlington, Oregon, became the first U.S. site to demonstrate plasma gasification technology to convert waste to fuel.

Sorbent Dialysis Allowed Patients Greater Freedom
Spinoff 1992: https://spinoff.nasa.gov/database/spinoffDetail.php?this=/spinoff//jsc/JSC-SO-89

Organon Teknika Corporation's REDY 2000 dialysis machine employed technology originally developed under NASA contract by Marquardt Corporation. The chemical process developed during the project could be applied to removing toxic waste from used dialysis fluid. This discovery led to the development of a kidney dialysis machine using "sorbent" dialysis, a method of removing urea from human blood by treating a dialysate solution. The process saved electricity, and because the need for a continuous water supply was eliminated, patients had greater freedom. The technology fell out of use, but researchers have talked about reviving it in the form of a "wearable kidney."

Cooling Suit Treated Medical Conditions
Spinoff 2005: https://spinoff.nasa.gov/Spinoff2005/ch_1.html

Based on its work with the liquid-cooling systems used to regulate astronaut body temperature in the spacesuit, ILC Dover created the Cool Vest, a lightweight cooling garment designed to reduce the effects of heat stress. It was used to lower the body temperatures of people suffering from hypohidrotic ectodermal dysplasia, a rare disease in which the sufferer is lacking in sweat glands, as well as to lessen the effects of heat-related symptoms in people suffering from multiple sclerosis. The vest also had applications in rigorous industrial environments where elevated temperatures can be debilitating. The Frederica, Delaware-based company no longer makes the product.

Insulation Kept Alaska Pipeline Oil Warm
Spinoff 1979: https://spinoff.nasa.gov/database/spinoffDetail.php?this=/spinoff//hdqs/HDQS-SO-91

Crude oil moving through 800 miles trans-Alaska pipeline must be kept at relatively high temperature—approximately 180 °F—to maintain the oil's fluidity. In the 1970s, the Space Division of the General Electric Company (GE) provided a product called Therm-O-Trol, a metal-bonded polyurethane foam especially formulated for Arctic insulation. Another problem was solved using Therm-O-Case, a double-walled oil well casing with multi-layered insulation to provide a protective barrier against heat transfer. Without it, heat transfer could have melted the frozen terrain and caused dislocation that could have destroyed expensive well casings. Both products evolved from work GE did on thermal management for Gemini, Apollo, and other NASA programs.

Hydrogen Generator Provided Cooling for Power Plant
Spinoff 1983: https://spinoff.nasa.gov/database/spinoffDetail.php?this=/spinoff//jsc/JSC-SO-84

Under contract to Johnson Space Center, General Electric Company developed a hydrogen generator for use in the fuel cell power system of the Gemini spacecraft. By 1982, the Sewaren generating station of Public Service Electric and Gas Company in New Jersey was using the technology to cool its large generators.

Controlled Blasts Allowed Quick Forced Entry, Demolition
Spinoff 1976: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19760009897.pdf

Explosive Technologies Inc. developed a linear blasting technique to separate stages of the Gemini launch vehicle. In the late 1960s, the company commercialized the technology as Jetaxe, which allowed firefighters to quickly cut entrances and ventilation holes, and the higher-powered Jetcord for controlled demolitions. The products were sold for about 10 years.

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