KEEPING OUR SIGHTS ON MARS PART 2: STRUCTURING A MOON-MARS PROGRAM FOR SUCCESS

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE AND AERONAUTICS

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED SIXTEENTH CONGRESS

FIRST SESSION

NOVEMBER 13, 2019

Serial No. 116–54

Printed for the use of the Committee on Science, Space, and Technology

Available via the World Wide Web: http://science.house.gov

U.S. GOVERNMENT PUBLISHING OFFICE
38–272PDF WASHINGTON : 2020

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Appendix II: Additional Material for the Record

KEEPING OUR SIGHTS ON MARS PART 2: STRUCTURING A MOON-MARS PROGRAM FOR SUCCESS

WEDNESDAY, NOVEMBER 13, 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 2:03 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 Part 2: Structuring a Moon-Mars Program for Success

Wednesday, November 13, 2019
2:00 p.m.
2318 Rayburn House Office Building

PURPOSE

The purpose of the hearing is to obtain perspectives on what is needed to establish a successful and sustainable Moon to Mars initiative, including information needed to inform decisions on the objectives, planning, architecture, acquisition, and implementation of a Moon to Mars initiative, among other factors.

WITNESSES

- **Lt. General Thomas P. Stafford**, USAF (Ret.); Member, National Academy of Engineering; Chairman, NASA ISS Advisory Committee; Pilot, Gemini 6, Commander, Gemini 9; Cdr. Apollo 10, Cdr. Apollo/ Apollo-Soyuz Test Program; Former USAF Deputy Chief of Staff for Research, Development and Acquisition

- **Mr. A. Thomas Young,** Former Director, NASA Goddard Space Flight Center, Former President and Chief Operating Officer, Martin Marietta Corporation

OVERARCHING QUESTIONS

- *What key decisions for a Moon-Mars initiative need to be made now, and what information and analysis should the Committee and Congress expect as the basis for such decisions?*
- *How important is a well-structured, integrated plan in developing a Moon-Mars initiative, and what elements should such a plan include? What models, if any, should be considered?*
- *What principles and criteria should guide the implementation of a Moon-Mars initiative, and what actions need to be taken in structuring a Moon-Mars program for success?*
- *How can Congress ensure that safety, sustainability, transparency, accountability, and affordability are prioritized when structuring a Moon-Mars program?*

BACKGROUND

The year 2019 marks 50 years since Americans sent the first humans to the surface of the Moon on the Apollo 11 mission, a monumental event of cultural, technological, and economic significance. The Apollo program continued for three more years until its final mission, Apollo 17, in 1972. While the United States continued to advance a human spaceflight program—developing and operating the Space Shuttle; developing, assembling, and continuously operating the International Space Station; and initiating the ongoing development of the Orion crew vehicle and Space Launch System—the nation has not explored deep space[1] with humans since the Apollo program ended over 40 years ago.

Over the decades since Apollo, Presidential initiatives to explore the Moon and Mars have been proposed, started, and cancelled or redirected. President George H.W. Bush established the Space Exploration Initiative in 1989 to send humans to Mars via the Moon. President George W. Bush created the Vision for Space Exploration in 2004 to return humans to the Moon. In 2010, President Barack Obama initiated an effort to first send humans to a near Earth asteroid and then eventually on a mission to Mars. Congressional direction, in successive NASA authorization acts, has authorized a stepping stone approach to human exploration of deep space, including to the Moon, Mars, and other destinations.[2]

Several blue-ribbon panels, advisory bodies, and Presidential Commissions have provided advice and recommendations on such initiatives and on the future of the nation's deep space human exploration program. Common topics considered in reports of those committees include objectives, architectures, planning, strategic approaches, risk, resources, capabilities, benefits, and other aspects regarding the implementation of a human deep space exploration program. Summaries of a subset of those reports are provided below.

Pioneering the Space Frontier (1986)[3]

Congress directed in the NASA Authorization Act of 1985 the establishment of a National Commission on Space to "*formulate a bold agenda to carry America's civilian space enterprise into the 21st century.*" In its report, "Pioneering the Space Frontier," the Commission proposed the following goals for the nation's civil space program: "*To lead the Exploration and Development of the Space Frontier, Advancing Science, Technology, and Enterprise, and Building Institutions and Systems that Make Accessible Vast New Resources and Support Human Settlements Beyond Earth Orbit, from the Highlands of the Moon to the Plains of Mars.*"

To accomplish these goals, the Commission proposed three broad objectives, or "thrusts:"

- "*Advancing our understanding of our Planet, our Solar System, and the Universe;*
- *Exploring, prospecting, and settling the Solar System; and*
- *Stimulating space enterprises for the direct benefit of the people of earth.*"

[1] "Deep space" generally means beyond low Earth orbit (LEO), about 1,200 miles above the Earth's surface.
[2] P.L. 109-155, The NASA Authorization Act of 2005; P.L. 110-422, The NASA Authorization Act of 2008; P.L. 111-267, The NASA Authorization Act of 2010; and P.L. 115-10, The NASA Transition Authorization Act of 2017.
[3] "Pioneering the Space Frontier: The Report of the National Commission on Space," May 1986. Available at: https://www.nasa.gov/pdf/383341main_60%20-%2020090814.5.The%20Report%20of%20the%20National%20Commission%20on%20Space.pdf

Two additional economic thrusts were included:

- *"Advancing technology across a broad spectrum to assure timely availability of critical capabilities; and*
- *Creating and operating systems and institutions to provide low-cost access to the space frontier."*

The Commission recommended a "*sustained step-by-step program to open the inner Solar System for exploration, basic and applied research, resource development and human operations."* Such a program would "*require creative partnerships of Government, industry and academia of the type that has proved highly productive in previous national enterprises."*

In developing the space agenda, the Commission highlighted the importance of ensuring the program is a worthwhile investment by the American people. The Commission accordingly identified three criteria a program must meet:

- *"Each element and increment of the program must be set in the context of a long-term plan;*
- *the program will be technically challenging, but feasible; and*
- *the program will be adequately funded."*

These themes and broad principles provided direction for the civil space program. The Commission also urged the Administration and Congress to work in concert to raise Americans' aspirations and to set new goals for civil space activities in which planned programs are carefully phased to create a well-understood, sustained national purpose. To do this, the Commission concluded that, "*long-range goals established by strong leadership will lead to a better-informed public, improved management of major national assets, accelerated technical progress, more economical operations, and greater private and international participation.*"

America at the Threshold (1991)[4]

In July 1989, President George H.W. Bush announced the Space Exploration Initiative (SEI), a vision to return United States astronauts to the Moon and then on to Mars within 30 years.[5] After an internal NASA study, a competing Lawrence Livermore National Laboratory (LLNL) plan, and a National Research Council Human Exploration study, President Bush gave NASA the mandate to move forward and organize a campaign to solicit ideas from industry, universities, national laboratories and the general public. This effort came to be known as the SEI Outreach Program. The ideas generated by this outreach effort were reviewed by the independent SEI Synthesis Group, chaired by Lieutenant General Thomas Stafford, U.S. Air Force (Ret.).

The Synthesis Group was "*chartered to provide two or more significantly different architectures, technology priorities and early accomplishments to support*" the SEI. The report, *America at the Threshold*, established several broad visions for the SEI: a) Knowledge of our Universe,

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[4] *America at the Threshold: Report of the Synthesis Group on Americas Space Exploration Initiative*, June 1991. Available at: https://history.nasa.gov/staffordrep/main_toc.PDF

[5] Portree, David S.F., *Humans to Mars, Fifty Years of Mission Planning, 1950-2000,* Monographs in Aerospace History #21, NASA SP-2002-4521.

b) Advancement in Science and Engineering, c) United States Leadership, d) Technologies for Earth, e) Commercialization of Space, and f) Strengthened U.S. Economy. To achieve these visions, the Synthesis Group report outlined four possible architectures: 1) Mars Exploration, 2) Science Emphasis for the Moon and Mars, 3) The Moon to Stay and Mars Exploration, and 4) Space Resource Utilization. The architectures had common aspects related to mission sizing, launching opportunities, duration and surface activities, but differed in approaches, emphases and program scope and scale to realize the SEI visions. The report identified 12 supporting technologies that required development *"to provide the tools necessary for safe and cost effective exploration."* These technologies included, but were not limited to, nuclear surface power, telerobotics and other robotics capabilities for rendezvous and docking large masses, and human factors for long duration space missions. The two most fundamental technologies were a heavy lift launch capability and nuclear propulsion.

In addition to technological capabilities, the report stressed the importance of organization and acquisition management, stating that *"[SEI] requires management that allows for crisp and timely decision making, plus the assured resources to reach its goals."* Drawing upon their examination of a *"number of successful and unsuccessful major aerospace, industry and government programs [and] various acquisition improvements,"* the Synthesis Group recommended NASA review its acquisitions process and undertake reforms, if necessary.

In addition to the recommendations, the Synthesis Group developed a set of guidelines and pitfalls for developing architectures. The guidelines were as follows:

1) *Establish crew safety as the number one priority.*
2) *Have clean lines of management authority and responsibility for all elements of the program - ensure that one organization or prime contractor is clearly in charge.*
3) *Establish realistic program milestones that provide clear entry and exit criteria for the decision process and create useful capabilities at each step.*
4) *Ensure that the Administration and the Congress clearly understand the technical and programmatic risks and realistic costs of the Space Exploration Initiative.*
5) *Mandate simple interfaces between subsystems and modules.*
6) *Make maximum use of modularity over the life of the program to maintain flexibility. Successive missions should build on the capabilities established by prior ones. Provide the capability to incorporate new technology as required.*
7) *Press the state-of-the-art in technology when required and/or when technological opportunities are promising with acceptable risk.*
8) *Ensure optimum use of man-in-the-loop. Don't burden man if a machine can do it as well or better, and vice versa.*
9) *Limit development times to no more than ten years. If it takes longer, the cost goes up and commitment goes down.*
10) *Focus technology development toward programmatic needs.*
11) *Minimize or eliminate on-orbit assembly requiring extravehicular activity.*
12) *Minimize mass to low Earth orbit to reduce cost.*
13) *Have redundant primary and separate backup systems. Design in redundancy versus heavy reliance on onboard/on-site maintenance.*
14) *Hire good people, then trust them.*

The pitfalls identified were:

1) *Establishing requirements that you will be sorry for; i.e., wish lists being treated as requirements and allowing requirements to creep.*
2) *Trying to achieve a constituency by promising too much to too many and "low balling" the technical and financial risks.*
3) *Committing to interminable studies and technology demonstrations without a firm commitment to execute a real program.*
4) *Not establishing configuration controls/baselines as soon as possible; e.g., weight and electrical power requirements.*
5) *Allowing software to run unchecked and become a program constraint rather than a supporting element.*
6) *Setting up agreements for development of program elements that are not under direct program management control.*
7) *Not saying "we were wrong" when we were wrong.*

Report of the President's Commission on Implementation of United States Space Exploration Policy: A Journey to Inspire, Innovate, and Discover (2004)[6]

In 2004, President George W. Bush announced a new Vision for Space Exploration (VSE), with the goal of sending human and robotic missions to the Moon, Mars, and beyond.[7] The President established an independent commission to make recommendations for implementing the VSE, appointing as commissioners nine experts from industry, government, academia, and the military, and, as chair, Edward C. "Pete" Aldridge, Jr. The commissioners published consensus recommendations in what is known as the Aldridge Commission report.

The Commission stated that a successful space exploration program must be:

1) "*sustainable over several decades,*" meaning, "*this will require the support of multiple Presidents, Multiple Congresses, and a couple of generations of American taxpayers. And at its core, the vision requires a sustained commitment from the American Public;*"
2) "*affordable with available resources,*" meaning a "*go as you can pay plan where we achieve periodic technological advances and discoveries based on what we can afford annually;*" and
3) "*credible in the stewardship of taxpayer dollars,*" meaning, "*the space exploration vision is neither sustainable nor affordable unless NASA's leadership of the exploration vision is deemed credible by the public and Congress.*"

To organize the initiative for success, the Commission found *"that the space exploration vision must be managed as a significant national priority, a shared commitment of the President, Congress, and the American people."* The vision may be led by NASA, but the Commission concluded that it could not be realized without the commitment of other government agencies, nations, commercial organizations, and researchers. To that end, the Commission recommended the President establish a Space Exploration Steering Council to coordinate all appropriate federal agencies in carrying out the VSE.

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[6] Report of the President's Commission on Implementation of United States Space Exploration Policy, June 2004. Available at: https://www.nasa.gov/pdf/60736main_M2M_report_small.pdf

[7] NASA, "President Bush Announces New Vision for Space Exploration Program," January 2004. Available at: https://history.nasa.gov/Bush%20SEP.htm

The Commission recommended that NASA *"adopt proven personnel and management reforms to implement the national space exploration vision."* The recommended reforms were built around three core concepts: combing thousands of discrete components and interdependent tasks in a single system-of-systems; having the lead systems integrator assume the management responsibility for any given program; and designing an exploration architecture that evolves iteratively and systematically, through a series of so-called "spiral developments." These management processes would guide long-term stewardship of the national vision.

According to the Commission, sustaining long-term exploration, however, cannot be a solely U.S. government endeavor. The Commission found that it requires a robust space industry that contributes to economic growth while leading the world in invention and innovation. The Commission also found that science was key to enabling the space vision and that NASA should seek input from the scientific community on exploration architectures. The Commission also highlighted the benefits of international partnerships and recommended implementing an architecture that would encourage global investment in support of the space vision.

Overall, the Commission reiterated that space exploration is a difficult task, requiring commitment from Administrations, Congress, and the American people. It also requires accepting failures along the way and a structure that can be quickly reorganized to fulfill a vision. The report concluded by stating, *"we must ask and answer bold question about the origins and our future. We must ponder innovate and search the depths of space to know our place in the cosmos."*

Seeking a Human Spaceflight Program Worthy of a Great Nation (2009)[8]

In 2009, the White House Office of Science and Technology Policy established the Review of U.S. Human Spaceflight Plans Committee *"to develop options in support of planning for U.S. human spaceflight activities beyond the retirement of the Space Shuttle."* The opening statement of the report clearly laid out the challenge: "*The U.S. human spaceflight program appears to be on an unsustainable trajectory. It is perpetuating the perilous practice of pursuing goals that do not match allocated resources.*"

The Committee identified five options for the human spaceflight program that considered the current programs of record, budgetary constraints and exploration goals. One was a baseline program that would implement the current program of record[9] within the existing budget. Two of the options were constrained to a flat or decreasing budget from 2010 to 2014. The fourth option focused on the Moon first, while the fifth option offered a flexible path focused on exploration as a strategy and could include lunar flybys, visits to Lagrange points and near-Earth objects.

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[8] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation,* October 2009. Available at: https://www.nasa.gov/pdf/396093main_HSF_Cmte_FinalReport.pdf

[9] The program of record at the time was the Constellation program which included the Ares I launch vehicle for a crewed mission to LEO; the Ares V heavy-lift launch vehicle for a crewed mission to the Moon; the Orion capsule to carry astronauts to LEO and beyond; and a lunar landing system.

The Committee established 12 criteria to guide their consideration of each option: 1) exploration preparation, 2) technology innovation, 3) science knowledge, 4) expanding and protecting human civilization, 5) economic expansion, 6) global partnerships, 7) public engagement, 8) schedule and programmatic risk, 9) mission safety challenges, 10) workforce impact, 11) programmatic sustainability, and 12) life-cycle cost. Based on these criteria, the Committee developed an evaluation process to asses each option. Using this process, they concluded that "*human exploration beyond LEO [was] not viable under the then budget conditions.* Furthermore, a meaningful program would require "*ramping up to approximately $3 billion per year in real purchasing power parity above the FY2010 budget guideline.*"

The Committee made several recommendations, including establishing clear mission goals focused on "why" rather than "where." They urged NASA to match resources to goals and identify the "*right mission and the right size.*" Another recommendation called for improving coordination between robotic and human exploration missions. The Committee also emphasized the need for stability, specifically noting that "*recurring budget ambiguities and reductions and redirections of policy, coupled with the high-fixed-cost structure of NASA, have not optimized the return on investment.*" The Committee encouraged the U.S. to engage with international partners, which could both improve foreign relations and add more overall resources to a human spaceflight program. Addressing management challenges, the Committee recommended generally that NASA organize appropriately to embark on a human spaceflight exploration mission, and particularly that "*the NASA Administrator needs to be given the authority to manage NASA's resources, including its workforce and facilities.*" In the area of workforce, the Committee encouraged greater flow of talent between industry and government, particularly as it relates to maintaining a world-class capability in systems engineering. The Committee also examined NASA's procurement options and recommended that the agency "*[utilize] the commercial authorities already granted to the agency, and [adopt] benchmarks in commercial practices utilized by other federal agencies.*"

Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration (2014)[10]

The NASA Authorization Act of 2010[11] directed NASA to engage the National Academies for a study that would review "*the goals, core capabilities, and direction of human spaceflight.*" In fulfilling that direction, 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,* a consensus study report of the Committee on Human Spaceflight.

The *Pathways* report concluded that a human spaceflight program must include sustainable—i.e., featuring human operation on a regular basis—presence beyond LEO and that the best way to achieve a sustainable human exploration program is to "*develop a program through the rigorous applications of a set of pathway principles.*" The committee defined a "pathway" as "*a specific sequence of intermediate accomplishments and destinations normally of increasing difficulty and*

[10] National Research Council, *Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration,* 2014, Washington, DC: The National Academies Press. Available at: https://www.nap.edu/catalog/18801/pathways-to-exploration-rationales-and-approaches-for-a-us-program
[11] Section 201, P.L 111-267.

complexity, leading to an ultimate (horizon) goal, with technology feed-forward from one mission to subsequent missions."

The top priority recommendation of the report was to adopt the following pathway principles:

I. Commit to designing, maintaining, and pursuing the execution of an exploration pathway beyond low Earth orbit toward a clear horizon goal.

II. Engage international space agencies early in the design and development of the pathway on the basis of their ability and willingness to contribute.

III. Define steps on the pathway that foster sustainability and maintain progress on achieving the pathway's long-term goal of reaching the horizon destination.

IV. Seek continuously to engage new partners that can solve technical or programmatic impediments

V. Create a risk-mitigation plan to sustain the selected pathway when unforeseen technical or budgetary problems arise. Such a plan should include points at which decisions are made to move to a less ambitious pathway (referred to as an "off-ramp") or to stand down the program.

VI. Establish exploration pathway characteristics that maximize the overall scientific, cultural, economic, political, and inspirational benefits without sacrificing progress toward the long-term goal."

As part of the sixth and final pathways principle quoted above, the report identified six desirable properties of pathways against which a given pathway option may be assessed, including that:

- "*the sequence of missions and destinations permits stakeholders, including taxpayers, to see progress and to develop confidence in NASA's ability to execute the pathway;*"
- "*the pathway is affordable without incurring unacceptable development risk;*" and
- "*the pathway supports, in the context of available budget, an operational tempo that ensures retention of critical technical capability, proficiency of operators, and effective use of infrastructure.*"

The report's second overall recommendation was that the Administration, NASA, and Congress adopt early and then rigorously apply a set of decision rules when challenges arise. The recommended decision rules included either not starting down a pathway or taking an "off-ramp" when it is clear that a pathway is not permitted by appropriated funding levels and five-year budget levels.[12] Recommended decision rules also included giving high priority to choices in development that "*solve important technological shortcomings, that reduce overall program cost, that allow an acceleration of the schedule, or that reduce developmental or operational risk,*" and that the human spaceflight program should divest itself, quickly, of any elements, infrastructure, or organizations that are *"no longer contributing to progress along the pathway.*"

[12] The study notes that budget projections may be unreliable, but they are also indispensable, suggesting that NASA could make the projections more robust by "*conduct[ing] sensitivity analysis and evaluat[ing] plans against a range of possible 5-year budget projections that may vary by 10 percent or more...[which] might be undertaken as part of the risk-mitigation plan.*"

Chairwoman HORN [Audio malfunction in hearing room]. Over the past 30 years, multiple blue ribbon panels, Presidential commissions, and advisory bodies have consistently set the Moon and Mars as goals for our human exploration programs. And as I've said before, I want Americans to be the first to set foot on the Red Planet. Sending Americans to land on and explore the surface of Mars is a monumental and worthy goal, one I believe we should embrace. Taking that giant leap will require every ounce of this Nation's commitment and capability. The critical questions before us now are, what decisions and actions are needed to structure a Moon and Mars program for sustainability and success?

We're here today to seek the guidance, and perspectives, and deep expertise of two eminent witnesses: One Apollo astronaut, and lead of one of the foundational studies on the Moon-Mars program, and a former industry executive, and director of NASA's Goddard Space Flight Center. They both have unparalleled depth and breadth of experience in human space flight, industry, and NASA programs. They have faced the hard technical challenges, seen what has worked and what hasn't. The lessons they have learned, and their wisdom are critical to our work here today.

We know that the road to sending American astronauts to Mars will require a commitment, dedication, and direction that continues across many Congresses and administrations. It is our job today to lay out a course that ensures consistency through these changes in leadership. Achieving such an audacious endeavor requires ambitious, yet realistic expectations, and the planning, leadership, workforce, and resources to increase the probability of success. Anything else runs the risk of perpetuating a cycle of human exploration visions left unmet.

The United States has led space exploration for over half a century. Our leadership role has changed the way we interact with the world, and the way the world perceives us. However, we cannot take our leadership for granted. Today our Nation has been without a domestic capability for sending humans into space for nearly a decade. At the same time, there are an increasing number of nations and private entities that are actively utilizing and growing their investment and capabilities in space. It is critical that we move beyond low Earth orbit, and that we do it sustainably, affordably, and safely. Any void we leave in that regard, others will fill.

The bottom line is we have a choice. Do we want to lead, or do we want to follow? Following is not the legacy our Apollo heroes deserve, especially as we celebrate the 50th anniversary of the Moon landing, nor is it a future that ensures the leadership, safety, and national security of America in space. Leading requires consistent purpose and direction, carrying out and achieving complex and challenging goals, and leading with partner nations and commercial industry in the peaceful exploration and uses of outer space.

Over the past 20 years we have had a taste of the cost and effort involved in leading and maintaining long-term human space flight activities. Developing, assembling, and operating the International Space Station (ISS) took over a decade to complete, and represented a U.S. investment of over $80 billion, and it requires

about $3 billion a year to support. Getting to the Moon and Mars will require much more. The decisions we make today about the structure of the Moon-Mars program extend beyond the next handful of years. They are about what we set up for future generations.

In a July 2019 article in *Physics Today*, one stakeholder stated, "Despite its successes, Apollo was canceled due to its expense, and NASA lacked any follow-on program." That is why it is imperative that we take this opportunity to hear from our witnesses on what it takes to create a sustainable and effective pathway toward sending humans to the Moon and Mars.

We, as a Nation, know what we are capable of achieving. We've landed humans on the Moon, supported humans living and working in space continuously for almost 20 years, landed and operated spacecraft on the surface of Mars, and much more. We must build on these hard-earned lessons as we look for innovative and expeditious ways to achieve our goals, while also ensuring the responsible use of taxpayer resources. It is our role on the Subcommittee and the Committee to structure a program that's in the best interest of the country, and has the greatest likelihood of success.

Before I close, I also want to make clear that our focus today, and in other exploration hearings, in no way minimizes the importance of NASA's science, space, technology, and aeronautics programs. All these missions contribute to NASA's success, and we need to ensure that they remain healthy and strong. I am excited to hear from our witnesses today, and glad to work with my colleagues on both sides of the aisle to ensure that NASA and our human space exploration programs are set up for success, both now and into the future.

[The prepared statement of Chairwoman Horn follows:]

Good afternoon and welcome. I'd like to extend a special thank you and welcome to our distinguished witnesses. We're honored to have you here with us today to continue an important conversation about our human exploration program.

Over the past 30 years, multiple blue-ribbon panels, Presidential Commissions, and advisory bodies have consistently set the Moon and Mars as goals for our human exploration program. And as I've said before, I want Americans to be the first to set foot on the Red Planet.

Sending Americans to land and explore the surface of Mars is a monumental and worthy goal - one I believe we should embrace. Taking that giant leap will require every ounce of this nation's commitment and capability.

The critical questions before us now are what decisions and actions are needed to structure a Moon and Mars program for sustainability and success?

We're here today to seek the guidance, perspectives, and deep expertise of two eminent witnesses-one Apollo astronaut and lead on one of the foundational studies on a Moon-Mars program, and a former industry executive and Director of NASA's Goddard Spaceflight Center. They have unparalleled depth and breadth of experience in human space flight, industry, and other NASA programs. They have faced the hard technical challenges, seen what has worked and what hasn't. The lessons they have learned and their wisdom are critical to our work today.

We know that the road to sending American astronauts to Mars will require a commitment and direction that continues across many Congresses and Administrations. It is our job to lay out a course that ensures consistency through those changes in leadership.

Achieving such an audacious endeavor requires ambitious yet realistic expectations and the planning, leadership, workforce, and resources to increase the probability of success. Anything else runs the risk of perpetuating a cycle of human exploration visions left unmet.

The United States has led space exploration for over a half-century. Our leadership role has changed the way we interact with the world and the way the world perceives us. However, we cannot take our leadership for granted.

Today, our nation has been without a domestic capability for sending humans into space for nearly a decade. At the same time, there are an increasing number of nations and private entities actively utilizing and growing their investments and capabilities in space.

It is critical that we move beyond low Earth orbit and that we do it sustainably, affordably, and safely. Any void we leave in that regard, others will fill.

The bottom line is we have a choice: do we want to lead or follow? Following is not the legacy our Apollo heroes deserve as we celebrate the 50th anniversary of the Moon landing. Nor is it a future that ensures the leadership, safety, and national security of America in space.

Leading requires consistent purpose and direction; carrying out and achieving complex and challenging goals; and leading with partner nations and commercial industry in the peaceful exploration and uses of outer space.

Over the past 20 years, we have had a taste of the cost and effort involved in leading and maintaining long-term human spaceflight activities. Developing, assembling, and operating the International Space Station took over a decade to complete, represented a U.S. investment of over $80 billion dollars, and requires about $3 billion a year to support. Getting to the Moon and Mars will require much more.

The decisions we make today about the structure of a Moon-Mars program extend beyond the next handful of years: they are about what we set-up for future generations. In a July 2019 article in Physics Today one stakeholder stated, ″Despite its success, Apollo was canceled due to its expense, and NASA lacked any follow-on program.″

That is why it is imperative that we take this opportunity to hear from our witnesses on what it takes to create a sustainable and effective pathway toward sending humans to the Moon and Mars.

We as a nation know what we are capable of achieving. We've landed humans on the Moon, supported humans living and working in space continuously for almost 20 years, and landed and operated spacecraft on the surface of Mars. We must build on those hard-earned lessons as we look for innovative, expeditious ways to achieve our goals while also ensuring responsible use of our taxpayer resources.

It is our role on the Subcommittee and the Committee to structure a program that's in the best interest of the country and that has the greatest likelihood of success.

Before I close, I want to make clear that our focus today and in other exploration hearings in no way minimizes the importance of NASA's science, space technology, and aeronautics programs. All of these missions contribute to NASA's success and we need to ensure they remain healthy and strong.

I look forward to our witness's testimonies and I'm grateful for the opportunity to work with my colleagues on both sides of the aisle to set NASA and our human exploration programs up for success now and into the future.

Chairwoman HORN. I now recognize Ranking Member Mr. Babin for an opening statement.

Mr. BABIN. Thank you, Madam Chair, I appreciate it. This summer we celebrated the 50th anniversary of the Apollo 11 Moon landing, and rather than resting on our laurels, the Trump Administration challenged NASA to return to the Moon on its way to Mars. This is an audacious goal. For over 15 years, multiple Congresses, controlled by both Republicans and Democrats, have passed authorization Acts that directed NASA to do the exact same thing. All of these Acts directed NASA to explore the Moon, Mars, and beyond using a stepping-stone approach. The laws directed NASA to efficiently develop technologies and architectures that enable further exploration and prevent dead-end technologies and missions. The laws direct NASA to leverage the expertise at NASA centers, and the work done on the Space Launch System (SLS) and Orion crew vehicle, that employ technologies derived from taxpayer investments in the Space Shuttle program.

Finally, Congress consistently directed NASA to explore deep space on a timetable determined by the availability of funding. The National Space Council, led by Vice President Pence, has adopted those principles for the Trump Administration. Space Policy Direc-

tive 1, or SPD–1, directs NASA to lead an innovative and sustainable program of exploration. SPD–1 also directed NASA to lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars, and to other destinations. The Administration should be commended for subsequently challenging NASA to achieve this goal by 2024.

For several years NASA has lacked a sense of urgency. Without a worthwhile near-term goal, our Nation's space enterprise lacked consistency and lacked focus. This allowed the previous administration to slash early stage funding for SLS and Orion, and to propose cuts year over year, stretch out development schedules, scale back capabilities, impose unique accounting rules like termination liability, and to hold up the purchase of long lead items during continuing resolutions. We now have bold leadership that is empowering NASA to lean forward.

NASA recently issued a broad Agency announcement soliciting proposals for a human landing system within 30 days. NASA directed contractors to not only propose landers that can launch on commercial launch vehicles. This is despite the fact that every space exploration study conducted over the last 40 years indicated that the most optimal architectures for exploring the Moon and Mars require a heavy lift launch vehicle similar to SLS. This strategy also fails to leverage the investments the taxpayer made over the last decade.

While I share the frustration and delays to the SLS program, switching horses mid-stream is not a wise move at this point. The Aerospace Safety Advisory Panel and the National Academies have all reported that one of the largest risks to the success of our human exploration program is a lack of consistency. It's also fair to note that other human exploration developments, like commercial crew, are also behind schedule.

At our last Space Subcommittee hearing, NASA said that maintaining the 2024 date for a lunar landing is unlikely if they do not receive the additional funding that they requested in their budget amendment. If a recent House Appropriations Committee hearing is any indication, the likelihood of receiving additional funding this year is dwindling. If this forces NASA to reassess its schedule for returning to the Moon, it would provide an opportunity to ensure that they are developing the ideal architecture that maximizes mission success, and minimizes risk. This could be done by developing landers that leverage the investments already made by the taxpayers, and national capabilities like SLS and Orion, and then relying on the private sector to contribute augmenting cargo capabilities, and delivering precursor sized payloads to the lunar surface. By this time NASA may have concrete funding details, and a more refined acquisition strategy.

I look forward to working with the Administration and my colleagues on both sides of the aisle here in Congress to make Artemis a success. I'd like to thank our two very distinguished guests and witnesses today for their service, and look forward to their testimony. So I yield back the balance of my time, Madam Chair. Thank you.

[The prepared statement of Mr. Babin follows:]

This summer we celebrated the 50th anniversary of the Apollo 11 Moon landing. Rather than resting on our laurels, the Trump Administration challenged NASA to return to the Moon on its way to Mars. This is an audacious goal.

For over 15 years, multiple Congresses, controlled by both Republicans and Democrats, have passed Authorization Acts that directed NASA to do the exact same thing. All of these Acts directed NASA to explore the Moon, Mars, and beyond using a ″stepping stone″ approach. The laws directed NASA to efficiently develop technologies and architectures that enable further exploration and prevent ″dead-end″ technologies and missions. The laws direct NASA to leverage the expertise at NASA centers and the work done on the Space Launch System (SLS) and Orion Crew vehicle that employ technologies derived from taxpayer investments in the Space Shuttle program. Finally, Congress consistently directed NASA to explore deep space on a timetable determined by the availability of funding.

The National Space Council, led by Vice President Pence, has adopted those principles for the Trump Administration. Space Policy Directive 1 (SPD-1) directs NASA to, ″[l]ead an innovative and sustainable program of exploration.″ SPD-1 also directed NASA to ″lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations.″

The Administration should be commended for subsequently challenging NASA to achieve this goal by 2024. For several years, NASA has lacked a sense of urgency. Without a worthwhile near-term goal, our Nation's space enterprise lacked consistency and focus. This allowed the previous Administration to slash early-stage funding for SLS and Orion, propose cuts year over year, stretch out development schedules, scale-back capabilities, impose unique accounting rules like ″termination liability,″ and hold up the purchase of long-lead items during continuing resolutions.

We now have bold leadership that is empowering NASA to lean forward. NASA recently issued a Broad Agency Announcement (BAA) soliciting proposals for a Human Landing System within 30 days. NASA directed contractors to only propose landers that can launch on commercial launch vehicles. This is despite the fact that every space exploration study conducted over the last 40 years indicated that the most optimal architectures for exploring the Moon and Mars require a heavy-lift launch vehicle similar to SLS. This strategy also fails to leverage the investments the taxpayer made over the last decade.

While I share the frustration in delays to the SLS program, switching horses midstream is not a wise move at the point. The Aerospace Safety Advisory Panel and the National Academies have all reported that one of the largest risks to the success of our human exploration program is a lack of consistency. Its also fair to note that other human exploration developments, like Commercial Crew, are also behind schedule.

At our last Space Subcommittee hearing, NASA said that maintaining the 2024 date for a Lunar landing is unlikely if they do not receive the additional funding they requested in their budget amendment. If a recent House Appropriations Committee hearing is any indication, the likelihood of receiving additional funding this year is decreasing. If this forces NASA to reassess its schedule for returning to the Moon, it would provide an opportunity to ensure that they are developing the ideal architecture that maximizes mission success and minimizes risk. This could be done by developing landers that leverage the investments already made by the taxpayer in national capabilities like SLS and Orion and relying on the private sector to contribute augmenting cargo capabilities and delivering precursor science payloads to the Lunar surface. By this time, NASA may have concrete funding details and a more refined acquisition strategy.

I look forward to working with the Administration and my colleagues here in Congress to make Artemis a success. I'd like to thank our two distinguished witnesses for their service, and look forward to their testimony. I yield back the balance of my time.

Chairwoman HORN. Thank you, Ranking Member. The Chair now recognizes the Chairwoman of the full Committee, Ms. Johnson, for an opening statement.

Chairwoman JOHNSON. Thank you, and good afternoon. I want to welcome both of our distinguished witnesses to today's hearing. Neither of you is a stranger to this Committee. We have benefited from your thoughtful perspectives and advice on multiple occasions, and I have no doubt that will be the case again today.

Your testimony comes at a particularly significant time. This Committee will be reauthorizing NASA this Congress, and a pro-

gram of human exploration beyond low Earth orbit that will ultimately take America to Mars is something we will be considering. I support a robust program of exploration that leads to Mars, but it needs to be one that is sustainable. Unfortunately, based on the limited information provided to date, the Administration's 2024 lunar landing directive appears to be neither executable, nor a directive that will provide a sustainable path to Mars.

Proponents of the Administration's crash program may argue that such a deadline will instill a sense of urgency and motivation into our space program. However, an arbitrary deadline that is uninformed by technical and programmatical realities, that is unaccompanied by a credible plan, and that fails to identify the needed resources and one that sets NASA up to fail, rather than enabling it to succeed. Not only does that do the hardworking men and women of NASA and its contractor team a real disservice, but it'll wind up weakening American leadership in space, rather than strengthening it. That is why I'm glad that Chairwoman Horn and the Space and Aeronautics Subcommittee have taken the time to strip away the rhetoric and examine what will actually be required to carry out a sustainable and effective program of human exploration leading to the first crewed landing on Mars.

And I can think of no better witnesses to help us understand what will be involved than the two individuals before us today. Each of them has decades of experience in aerospace, and they speak with deep understanding of what will be needed to successfully carry out an ambitious program for human exploration. That doesn't mean that we should simply try to recreate the Apollo program. Apollo was a unique undertaking carried out during a unique time in our history. But we do need to understand the factors that made Apollo and other major space flight programs successful, including a skilled management team; a hardnosed approach to design, and operations, and risk; an understanding of the pros and cons of the available technological options; a commitment to testing; and a willingness to commit the necessary resources. As we embark upon this generation's human exploration adventure, we face many of the same challenges as those who led Apollo faced. While we need not be bound by the past, we do need to take heed of its lessons, some of which were painfully learned.

In closing, I believe that my friends and colleagues on both sides of the aisle want a human exploration program for America that is bold and visionary, and worthy of our great nation. I believe we can have one, if we take the time to get it right. This hearing is an important step in that process, and I look forward to our discussion. Thank you, and I yield back.

[The prepared statement of Chairwoman Johnson follows:]

Good afternoon. I want to welcome both of our distinguished witnesses to today's hearing. Neither of you is a stranger to this Committee. We have benefited from your thoughtful perspectives and advice on multiple occasions, and I have no doubt that that will be the case again today.

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Thank you, and I yield back.

Chairwoman HORN. Thank you, Madam Chairwoman. And at this time the Chair recognizes Ranking Member, and fellow Oklahoman, Mr. Lucas for his opening statement, and introduction of another fellow Oklahoman.

Mr. LUCAS. Thank you, Madam Chair. Tomorrow marks the 50th anniversary of Apollo 12's launch. November 14, 1969, Pete Conrad, Alan Bean, and Richard Gordon set off on humanity's second mission to the lunar surface. Despite harrowing winds and lightning strikes that overloaded the spacecraft's fuel cells during the launch, the mission's success proved America's resolve to explore space. It demonstrated that Apollo 11 wasn't a fluke, or a one-time achievement, but rather the dawn of a new era for mankind.

The missions after Apollo 11 may not have been as celebrated, but they solidified America's leadership in space, and were just as valuable to our studies of the moon. But what if we did not return to the Moon after Apollo 11? And thankfully we did, and we followed that up with a string of successful launches, culminating in Apollo 17. Unfortunately, we haven't been back to the Moon since Gene Cernan left his daughter's initials in the lunar dust in 1972 on Apollo 17. That's 47 years, nearly a half a century.

I can't help but draw comparisons to the current state of human space exploration. Rather than canceling a return to the Moon by saying we've been there before, the Trump Administration set a bold course to return to the Moon, and assure American leadership in space. Just as Apollo 12 affirmed America's resolve last century, the Administration's plans to return to the Moon will demonstrate our resolve and leadership in this century. This is because we have

the potential to learn much more now than we did a half a century ago.

Just last week NASA scientists opened an untouched sample of lunar rocks collected during Apollo 17. We kept those samples preserved for nearly 50 years because we knew our technology would advance rapidly in the years following Apollo 17, and we could learn more from analyzing them now, in pristine conditions, than we could've at the time. Similarly, returning to the Moon now will help us develop the technology necessary to land humans on Mars. It will allow our astronauts to learn how to operate in deep space, and on the surface of another world only a few days away, rather than months or years away. The Artemis program has already energized the NASA workforce, motivated contractors, inspired scientists and students.

Artemis will require marshaling our Nation's best and brightest, as well as significant contributions from our international partners and the private sector. This is a worthwhile task because great nations do great things. As we set forth on our return to the Moon, we should always be mindful of the lessons we learned from Apollo and the decades that followed. Progressing incrementally on successful achievements, limiting the number of mission elements to decrease risk, and maintaining consistency of purpose are lessons that are just as relevant today as they were 50 years ago.

Luckily we have two great witnesses who I'm sure can add to this list for us. And as the Chairman noted, one of those witnesses is a fellow Oklahoman, Lieutenant General Thomas Stafford, Retired. He grew up in Weatherford, Oklahoma, which I proudly represent. After attending the Naval Academy, and serving as an Air Force test pilot, he was selected for astronaut group number two in 1962. He went on to fly aboard Gemini 6A, Gemini 9, Apollo 10, and Apollo-Soyuz Test Project. He served as a director of the Astronaut Office, commanded the Air Force Flight Test Center at Edwards Air Force Base, and was Deputy Chief of Staff, Research, Development, and Acquisition at the Pentagon. Since retirement, he served as the Chairman of the International Space Station Advisory Committee, chaired the Synthesis Group that produced the report entitled, "America at the Threshold: On the Space Exploration Initiative." His awards are too numerous to mention, but probably his finest accomplishment is being born in Western Oklahoma, where, I would note, his namesake, the Stafford Air and Space Museum, resides. I'm proud to call him a constituent, a friend, a confidant.

Thank you for holding this hearing, Madam Chair. I yield back the balance of my time, and look forward to the testimony.

[The prepared statement of Mr. Lucas follows:]

Tomorrow marks the 50th anniversary of the Apollo 12 launch. On November 14, 1969, Pete Conrad, Alan Bean, and Richard Gordon set off on humanity's second mission to the lunar surface. Despite harrowing winds and lightning strikes that overloaded the spacecraft's fuel cells during the launch, the mission's success proved America's resolve to explore space. It demonstrated that Apollo 11 wasn't a fluke or a one-time achievement, but rather the dawn of a new era for mankind.

The missions after Apollo 11 may not have been as celebrated, but they solidified America's leadership in space and were just as valuable to our studies of the Moon. But what if we did not return to the Moon after Apollo 11? Thankfully we did, and we followed that up with a string of successive missions culminating with Apollo 17. Unfortunately, we haven't been back to the Moon since Gene Cernan left his

daughter's initials in the lunar dust in 1972 on Apollo 17. That's 47 years - nearly half a century.

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This is because we have the potential to learn much more now than we did a half century ago. Just last week, NASA scientists opened an untouched sample of lunar rocks collected during Apollo 17. We kept those samples preserved for nearly 50 years because we knew our technology would advance rapidly in the years following Apollo 17 and we could learn more from analyzing them now, in pristine condition, than we could at the time.

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One of those witnesses, Lieutenant General Thomas Stafford (Ret.), grew up in Weatherford, OK, which I proudly represent. After attending from the Naval Academy and serving as an Air Force test pilot, he was selected for Astronaut Group 2 in 1962. He went on to fly aboard Gemini 6A, Gemini 9, Apollo 10, and the Apollo-Soyuz Test Project. He served as Director of the Astronaut Office, commanded the Air Force Flight Test Center at Edwards Air Force Base, and was the Deputy Chief of Staff, Research Development and Acquisition at the Pentagon.

Since retirement, he served as the Chairman of the International Space Station Advisory Committee and chaired the Synthesis Group that produced the report titled ″America at the Threshold″ on the Space Exploration Initiative.

His awards are too numerous to mention, but probably his finest accomplishment is being born in western Oklahoma, where his namesake, the Stafford Air and Space Museum resides. I am proud to call him a constituent, a friend, and a confidant.

Thank you for holding this hearing, Madam Chairwoman. I yield back the balance of my time.

Chairwoman HORN. Thank you, Ranking Member Lucas. It is truly an honor to have you both here today. If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point. And, without objection, I'm submitting for the record a letter from the Planetary Society. OK. Wonderful.

So we've had an introduction of one of our witnesses, and I have to say that one of the really fantastic things about the work that we get to do on this Committee is that we're doing the work of the Nation, and we're doing it in a way that exemplifies what we should be doing, working in a bipartisan manner to address the issues ahead of us, and set this up for success, and that includes the recognition of the witnesses in front of us today that I don't think you'll find any disagreement about the expertise and the experience of our witnesses. And I'd like to take a moment now to introduce our other distinguished witness, who, like General Stafford, has his own remarkable career.

Our second witness today is Mr. A. Thomas Young, former NASA Goddard Director and aerospace industry executive. Mr. Young

began his career at the Langley Research Center, where he was the Mission Director for Project Viking, which successfully landed two Viking spacecraft on Mars. He also served as the Director of the Planetary Program at NASA Headquarters, and was Deputy Director of NASA Ames Research Center. He then went on to become Director of NASA's Goddard Space Flight Center.

After leaving NASA in 1982, Mr. Young transitioned to industry, and became President and Chief Operating Officer of Martin Marietta Corporation, an aerospace manufacturing corporation that later merged with Lockheed Corporation to form what is now known as Lockheed-Martin Corporation. Mr. Young is the fellow of numerous prestigious organizations, including the American Institute of Aeronautics and the American Astronautical Society, the Royal Astronautical Society, and the International Academy of Astronautics.

Mr. Young received both a bachelor's degree in aeronautical engineering and a bachelor's degree in mechanical engineering from the University of Virginia. He also received a master's of management degree from MIT, and an honorary doctorate of science from Salisbury University. Welcome, Mr. Young.

As our witnesses, you should know you will each have 5 minutes for your spoken testimony. Your written testimony will be included in the record for the hearing, and when you've completed your spoken testimony, we will begin with questions. Each Member will have 5 minutes to question the panel, and we'll start today with General Stafford. General Stafford, you're recognized.

TESTIMONY OF LIEUTENANT GENERAL THOMAS P. STAFFORD, MEMBER, NATIONAL ACADEMY OF ENGINEERING, CHAIRMAN, NASA ISS ADVISORY COMMITTEE; PILOT, GEMINI 6; CDR. GEMINI 9; CDR. APOLLO 10; CDR. APOLLO/APOLLO-SOYUZ TEST PROGRAM; AND FORMER USAF DEPUTY CHIEF OF STAFF FOR RESEARCH, DEVELOPMENT, AND ACQUISITION

Lt. Gen. STAFFORD. Chairwoman Horn, Ranking Member Babin, Committee Members, and also full Committee Chairwoman, friend, Bernice Johnson, and Ranking Member Lucas, thank you for this opportunity to address the current state of NASA exploration beyond low Earth orbit. And over the years I've had the opportunity to testify before both the Subcommittee and the full Committee for many years, and I've always applauded this Subcommittee and the Committee for your continued bipartisan support for the guidance and the legislation to ensure the United States has a strong world leadership in space exploration.

And, going back a few years to the NASA 2010 authorization bill, it was really superb to see the bipartisan work of both the House and the Senate, and then the House and the Senate working together, that gave us the authorization under which we have the SLS and the Orion spacecraft today. And, from my observation of that, being a little bit involved in that, if all the Members of the U.S. Congress, the House and the Senate, worked like that, the congressional approval rating would be up in the 60 or 70 percent,

believe me. But the 2010 authorization bill was just superb, so thank you for all the help.

As pointed out, this is the 50th anniversary of the Apollo program I remember so well, and it was 50 years ago that I flew to the Moon. I was commander of Apollo 10, and also, to Congressman Lucas, I certainly appreciate those kind words of introduction for just a redneck gray haired space cowboy from Western Oklahoma. But as we look at where we are going forward, it's going to be difficult. It's going to be tough. And I'm reminded of the words of the great writer George Santayana, to paraphrase it, those that ignore the lessons of history are doomed to repeat them. And as we start down here with the Artemis program, we have to be aware of all the triumphs and the tragedies that we've had in the past.

Now, in 1989, the 20th anniversary of Apollo 11, President George H.W. Bush gave a speech on the steps of the Smithsonian Air and Space Museum. He set the space policy for returning to the Moon after the turn of the century then, and then—back to stay, he said, and then eventually a manned mission to Mars. That became known as the Space Exploration Initiative. Then Vice President Quayle was then appointed to activate the National Space Council. And then, after a couple of small studies, I was asked by Vice President Quayle and President Bush if I would chair a committee to put together and synthesize the ideas of how to go back to the Moon, on to Mars, in a way that's faster, better, safer, and lower cost.

So I donated about 60 percent of my time, had two floors of people over in Crystal City, 45 people full time. We had people from all around the United States, industrial firms came in, and at the end of 11 months the Vice President and I had a joint press conference at the White House and unveiled this book—kind of known as the Bible for exploration beyond low Earth orbit called, "America at the Threshold." And one of the major things that came out in my charter was two or more architectures, and the technology priorities. We had 14 technology priorities, and we ended up with four architectures, but the number one was that this country build a heavy lift booster that would go from 150 metric tons to grow to 250 metric tons. And we outlined this out of parts and pieces from the Saturn V to reduce the cost. And hopefully we will be able to get there someday, even though the booster we have now is small, compared to that. Thank you, Madam Chair.

[The prepared statement of Lt. Gen. Stafford follows:]

Hearing of the House Committee on Science, Space, and Technology Subcommittee on Space and Aeronautics

"Developing Capabilities for NASA Space Exploration: Beyond Lunar Orbit"

Wednesday, November 13, 2019

Testimony of Lt. General Thomas P. Stafford, USAF (Ret.)

Chairwoman Horn, Ranking Member Babin and Committee Members, thank you for this opportunity to address the current state of NASA Exploration beyond low Earth orbit. I have had the opportunity to testify before this subcommittee and the full Committee many times over the past 50 years. I have always applauded this Committees continued bipartisan support and guidance over the years to insure the United States has strong world leadership in space exploration.

This year, we are celebrating the 50th Anniversary of the Apollo Program and the Anniversary of Apollo 11's first landing on the moon. Numerous lessons from Gemini, Apollo, Space Shuttle, Space Station, and Exploration Programs come to mind that should be heeded as we prepare to return explorers beyond low Earth orbit, first to the Moon and then to Mars.

Discussions today will be about the current status of the exploration program. I am reminded of the words of the great writer George Santayana, "Those that ignore the lessons of history are doomed to repeat them." Hopefully NASA will be successful in carrying out the space policy of the Administrations Exploration Program of returning to the Moon and eventually an expedition to Mars.

I joined NASA with the 2nd group of nine astronauts in 1962 who flew majority of the Gemini and Apollo flights. I served as backup pilot of the first Gemini flight, then flew as pilot of Gemini VI that performed the first Rendezvous in space and validated the techniques that would prove the key maneuver in the Apollo program of landing on the moon. I then flew as Commander of Gemini IX and flew three different types of rendezvous, one of which would be standard for the lunar missions. I then served as backup Commander for the first Apollo flight, Apollo VII and then commanded Apollo X which included the first flight of the lunar module to the Moon. The lunar module was too heavy to land when I descended to nine miles of the moon. I photo mapped, radar mapped and visually surveyed the potential lunar landing site and then performed the first rendezvous around the Moon. On the return to the Earth, with my crew, set the all-time world human speed record of 24,791 MPH or Mach 36.

After Apollo X, I replaced Alan Shepherd as Chief of the Astronaut Office and after several years there became Deputy Director of Flight Crew Operations. I then served as Commander of the Apollo-Soyuz test program, the

first International rendezvous and docking with Soviet Cosmonauts. This mission laid the foundation for Shuttle-Mir program and international flight cooperation with other countries and now the International Space Station program. I have served since 1995 as Chairman of the International Space Station advisory task force to review safety and operational readiness of the program.

In 1989, on the 20th anniversary of Apollo 11, President George H.W. Bush gave a speech on the steps of the Smithsonian Air and Space Museum. He set the human space policy for returning to the Moon- "Back to Stay," and a "Manned Mission to Mars." This began what came to be known as the "Space Exploration Initiative." He reactivated the National Space Council with Vice President Dan Quayle as Chairman. After several small studies by NASA and the NRC, Vice President Quayle asked me if I would volunteer to form a study group that could outline the steps that could better carry out President Bush's space vision in a way that was faster, better, safer, and at a lower cost. I assembled a group of forty-five individuals from NASA, DOD, DOE, Industry with experience in the area of space exploration. I had a second group headed by the Commander of USAF Space

and Missiles Organization that consisted of 150 members from all three branches of the DOD to support our effort. We also had the RAND Corporation that had an 800 number that would take ideas from all over America and sort the viable ones that their opinion did not violate the laws of physics and could have a potential positive input to the study. All the aerospace in the USA and other interested industrial firms could make presentations to us on their approach on what they could contribute to the goal of returning to the Moon and going on to Mars. Also, had a Senior Steering Group headed by Dr. Robert Seamans of M.I.T. that checked our progress and critiqued our findings as we progressed in the study. These members included Dr. Christopher C. Kraft and Dr. Max Faget of NASA/JSC. Our charter was to produce two or more architectures and the technology priorities to carry out President Bush's Space Exploration Initiative.

At the end of eleven months, in June 1991, Vice President Quayle and I had a joint press conference at the White House press room and unveiled the findings of the study titled "America at the Threshold." I outlined the four potential architectures and the supporting technologies to carry out the architectures. The number

one of the supporting technologies identified was the reinstitution of a heavy weight launch vehicle that was larger than the Saturn V. The synthesis group then gave NASA eighty-three boxes of data it had collected on the various subjects we had investigated, and the synthesis group was dissolved.

The Bush Administration started to implement the Space Exploration Initiative. When Bill Clinton became President in January 1993, he terminated the Space Exploration Initiative.

President George W. Bush in 2004 outlined his Space policy which was termed "Vision for Space Exploration" which was followed by the NASA Authorization Act of 2005. To carry out this policy over 300 people from the NASA centers produced a extensive study called Exploration Systems Architectural Study. One of the major factors that enabled this architecture to be feasible was a heavy lift launch vehicle constructed of parts from the space shuttle program and other entities. It resulted in a booster that would deliver 410 thousand pounds into low Earth orbit which would produce a

translunar injection mass of approximately 136,600 pounds. It will also have a large shroud that could encompass habitats, rovers and other elements of infrastructure that would be required for a potential permanent lunar base. The program to carry this out was termed the Constellation program. This was supported by the Congress until the inauguration of President Obama in January 2009 and an immediate 20% reduction in the budget by the OMB. A study was started under the leadership of Mr. Norm Augustine, former Chairman of Lockheed Martin which outlined their findings which stated the present program was unsustainable at that budget level. There was no place in the study that recommended cancellation of the program. However, in February 2010, the Obama Administration cancelled the program. Immediately a bipartisan letter signed by 29 members of the House and Senate stated that none of the contracts by the Constellation program should be terminated. The NASA Authorization Act of 2010 authorized the development of a heavy lift booster termed the Space Launch System which would deliver a minimum of 70 metric tons to LEO to start with and grow to a minimum of 130 metric tons to LEO and also authorized the development of a space craft capable of

flying both to the Moon and eventually to Mars and could encompass a crew of up to 6 people. It was termed the Orion spacecraft. The Appropriations Committees funded the booster and spacecraft using in excess of what was requested under the President's budget from this time to the present.

In 2014, the National Research Council of Aeronautics, Space, and Engineering Board produced a study that reviewed the expiration of Space beyond low Earth orbit. It outlined the fact that what is required is a heavy lift booster to provide the transportation from Earth to the Moon and Mars.

In 2019, a team at the NASA Marshall Space Flight Center conducted a study on the choice of the human lunar mission balance of launch vehicle manifesting and the schedule realities. It determined that SLS is essential for architecture and mission closure.

- Only SLS can lift the Orion Spacecraft
- SLS cargo significantly simplifies the mission

- SLS Block 1B opens up trade space and provides robust architecture

President Trump set a goal of returning to the Moon by 2024. NASA will have to make bold decisions and utilize a lot of the management techniques used during Apollo program. The leadership capability at NASA must be augmented at headquarters and at the applicable centers. The execution of a large complex program will require adequate systems engineering, integration and an appropriate budget to carry this out. The Congress will also need to produce adequate legislation to support this effort. Utilizing NASA and the aerospace industry as implementations capable of achieving this noble goal.

Thank you and I welcome your questions.

OFFICIAL BIOGRAPHY
Lt. General Thomas P. Stafford, USAF (Ret.)
NASA Astronaut (Former)

PERSONAL DATA: Born September 17, 1930, in Weatherford, Oklahoma. Married to the former Linda Ann Dishman of Chelsea, Oklahoma. They have two sons, Michael Thomas and Stanislav "Stas" Patten. First marriage was to the former Faye L. Shoemaker. They had two daughters, Dionne Kay and Karin Elaine as well as two grandsons, Thomas P. Stafford II and Andrew Alexi Harrison. Linda has two children from a previous marriage, Kassie Neering and Mark Hill, and four grandchildren: Sloane, Lee, Marcus, and Tara. He enjoys hunting, scuba diving, fishing, weight lifting, Pilates, and swimming.

EDUCATION: Graduated from Weatherford High School, Weatherford, Oklahoma; received a Bachelor of Science degree (with honors) from the United States Naval Academy in 1952. In 1958, he then attended the United States Test Pilot School, graduating in 1959, and was awarded the A.B. Honts Award as the outstanding graduate.

In addition, General Stafford is the recipient of many honorary degrees, including doctorate of humane letters, University of Oklahoma; a doctorate of laws from the University of Cordoba, Argentina; doctorate of humane letters, Oklahoma State University; doctorate of communications, Emerson College, Boston, Massachusetts; a Masters and Doctorate of human letters, Southwestern Oklahoma State University, Weatherford, Oklahoma; a doctorate of laws, Western State University, Los Angeles, California; a doctorate of science from Oklahoma City University; a doctorate of aeronautical engineering, Embry-Riddle Aeronautical University, Daytona Beach, Florida; and a doctorate of humanities, Oklahoma Christian College, Edmond, Oklahoma.

ORGANIZATIONS: Member, National Academy of Engineering; Fellow of the American Institute of Aeronautics and Astronautics (AIAA); Fellow of the American Astronautical Society; the Society of Experimental Test Pilots; and a member of the Masonic Lodge.

SPECIAL HONORS: Congressional Space Medal of Honor; Presidential Medal of Freedom; Wright Brothers Memorial Trophy; Harmon International Aviation Trophy (2x); Federation Aeronautique Internationale Gold Space Medal; American Institute of Aeronautics and Astronautics (AIAA) Chanute Flight Award; National Geographic Society's General Thomas D. White USAF Space Trophy; Veterans of Foreign Wars National Space Award; National Academy of Television Arts and Sciences Special Trustees "Emmy" Award; Society of Experimental Test Pilots James H. Doolittle Award for Management; Rotary National Award for Space Achievement (RNASA); National Aviation Hall of Fame; National Astronaut Hall of Fame; the Aerospace Walk of Honor; the State of Oklahoma Hall of Fame; Oklahoma Commerce and Industry Hall of Honor; and selected as the Oklahoma Aviator of the Century.

Awards from the National Aeronautics and Space Administration include NASA's Distinguished Service Medals (4x), Exceptional Service Medals (2x), and NASA's Medal for outstanding leadership (one of the agencies highest awards). He served as the Chairman of the Operations Oversight Committee of the first Hubble Telescope Spacecraft Servicing and Repair Mission that corrected the design and manufacturing defect of the instrument, and he received NASA's Public Service Award for the Hubble Telescope Service and Repair Mission for his tremendous efforts to help save the orbiting telescope.

Military honors include the Air Force Distinguished Flying Cross with one Oak Leaf Cluster, Distinguished Service Medal (4x), Air Force Outstanding Unit Award with one Oak Leaf Cluster, Air Force Commendation Medal, the Air Force Command Pilot Astronaut Wings, the USAF's Lifetime Achievement Award, and designated as a Distinguished Graduate of the U.S. Naval Academy.

EXPERIENCE: General Stafford graduated with honors in 1952 from the U.S. Naval Academy, Annapolis, Maryland, and was commissioned a second lieutenant in the United States Air Force. He

received his pilot's wings at Connally AFB, Waco, Texas in September 1953. He completed advanced interceptor training and was assigned to the 54th Flight Interceptor Squadron, Ellsworth AFB, Rapid City, South Dakota. In December 1955, he was assigned to the 496th Fighter Interceptor Squadron, Hahn Air Base, Germany, where he performed the duties of pilot, flight leader, and flight test maintenance officer, flying F-86Ds. He attended the USAF Experimental Test Pilot School, and received the A.B. Honts award for outstanding graduate. He became an instructor in flight test training, and specialized academic subjects, establishing basic textbooks and directing the writing of flight test manuals for use by the staff and students. He is co-author of the Pilot's Handbook for Performance Flight Testing and the Aerodynamics Handbook for Performance Flight Testing.

General Stafford was selected among the second group of astronauts in September 1962 by the National Aeronautics and Space Administration (NASA) to participate in Projects Gemini and Apollo. In December 1965, he piloted Gemini VI and performed the first rendezvous in space, and helped develop techniques to prove the basic theory and practicality of space rendezvous. In June 1966, he commanded Gemini IX and performed a demonstration of an early-phase rendezvous that would become standard in later Apollo lunar missions, the first optical rendezvous, and demonstrated a lunar orbit abort rendezvous.

From August 1966 to October 1968, Stafford headed the mission planning analysis and software development responsibilities for the astronaut group for Project Apollo. He was the lead member of the team that helped formulate the sequence of missions leading to the first lunar landing mission. He demonstrated and implemented the theory of a pilot manually flying the giant Saturn V booster into orbit, and the technique for the critical translunar injection maneuver.

In May 1969, Stafford would command the Apollo 10 mission to the moon, piloting the first Lunar Module (LM) into lunar orbit. The highly successful mission was the final full-scale dress rehearsal for a lunar landing that would happen during the Apollo 11 mission just two months later. Stafford flew the LM down to within nine miles of the moon's surface designating the landing ellipse for the first landing, performed the first lunar rendezvous, conducted reconnaissance on future Apollo landing sites, and proved all the necessary elements of the lunar landing, with the exception of the actual landing itself.

During the Apollo 10 reentry, General Stafford and his crew was recognized by the Guinness Book of World Records for reaching the highest speed ever attained by man, when the spacecraft reached a speed of 24,791 statute miles per hour – Mach 37. This ultimate speed record still holds today, and may not be exceeded until an astronaut crew returns from a mission to Mars.

Following his return from the moon, Stafford was assigned as the Chief of the Astronaut Office in June 1969, and was responsible for the selection of flight crews for Projects Apollo and Skylab. He reviewed and monitored flight crew training status, and was responsible for coordination, scheduling, and control of all activities involving NASA astronauts.

In June 1971, General Stafford was named as the Deputy Director of Flight Crew Operations at the NASA Manned Space Flight Center (later known as the Johnson Space Center) in Houston. He was responsible for assisting the center director in planning and implementation of programs for the astronaut group, Aircraft Operations, Flight Crew Integration, Flight Crew Procedures, and Crew Simulation and Training Divisions.

Stafford would become the first general to fly into space when he logged his fourth space flight as Apollo commander of the Apollo-Soyuz Test Project (ASTP) mission, July 15-24, 1975. This mission would be the first international space flight, and would be a joint mission culminating in the historic "first handshake in space" between American astronauts and Soviet cosmonauts. Historians now consider the mission as the beginning of the end of the Cold War, and for his efforts, General Stafford was nominated for the Nobel Peace Prize.

General Stafford was promoted to the grade of Major General in August 1975. He left NASA in November 1975 to assume the command of the Air Force Flight Test Center at Edwards AFB, California. As part of his responsibilities, he also assumed the operational command of the Groom Lake

Test Facility (better known as "Area 51") in Nevada, the Hill-Dougway-Wendover Test Range in Utah, and the Parachute Test Facility in El Centro, California. During his tenure, he was responsible for the testing oversight of the F-15, YF-16, YF-17 (later to become the F-18), the A-10, B-1A, YC-14, YC-15, C-141B, Air Launch Cruise Missile (ALC), "Have Blue" (the first experimental stealth aircraft), and the safety and operations oversight of the Approach and Landing Test (ALT) Program for the Space Shuttle.

Stafford was promoted to Lt. General in March 1978, and in May 1978 assumed the duties as the USAF Deputy Chief of Staff for Research, Development and Acquisition, HQ USAF, Washington, D.C. In addition to the standard duties of his position, in 1979, General Stafford personally initiated the development of the F-117A stealth fighter program. Stafford then wrote the initial design specifications for, and started the Advanced Technology Bomber development (ATV) Program (later renamed the B-2A Stealth Bomber) even though no statement-of-need or requirements existed. He initiated the Advanced Cruise Missile program, designated as the AGM-129 Stealth Cruise Missile, and started the F-110 Afterburning Turbo-Fan Fighter engine program. He also initiated what would become the roadmap for the Advanced Tactical Fighter (ATF), which would become the F-22A Stealth Fighter. General Stafford retired from the Air Force in November 1979.

By the end of his military and NASA career, General Stafford would become the first member of his Naval Academy Class of 1952 to pin on the first, second and third stars of a General Officer. He has flown six rendezvous in space; logged 507 hours and 43 minutes in space flight time, and wears the Air Force Command Pilot Astronaut Wings. He has flown over 127 different types of aircraft and helicopters, four different types of spacecraft, and rode three different types of boosters into space.

In December 1979, former California Governor Ronald Reagan asked Stafford to join his 1980 presidential campaign team as his Air Force defense advisor, and was on Reagan's transition team after his election as President in November 1980.

In June of 1990, Vice-President Dan Quayle and the NASA Administrator asked General Stafford to form and become Chairman of a team to independently advise NASA how to carry out President Bush's Space Exploration Initiative, his vision of permanently returning to the moon, and then go on to explore Mars. Stafford assembled teams of 40 full-time and 150 part-time members from the DOD, DOE, NASA, as well as obtaining inputs from academia, and many industrial groups to conduct the one year comprehensive study. The result was *"America at the Threshold,"* a road map for the next 30 years of the U.S. Manned Space Flight Program. General Stafford and Vice-President Quayle held a joint press conference at the White House in June 1991 to announce the recommendations to the public.

In 1994, the Clinton Administration directed a review of all federally-funded research and development plans of the Executive Branch. General Stafford chaired the committee to review and make recommendations to enhance the efficiency of the R&D initiatives of the NASA Human Exploration Enterprise that included the NASA Centers at JSC, KSC, MSFC and SSFC.

Stafford co-founded the technical consulting firm of Stafford, Burke, and Hecker, Inc. in Alexandria, Virginia. He has served on the Board of Directors of numerous corporations listed on the New York Stock Exchange and the American Exchange. He has served as an advisor to a number of governmental agencies, including NASA and the Air Force Systems Command (later named the Air Force Materials Command).

Stafford would also serve on the National Research Council's Aeronautics and Space Engineering Board, the Committee on NASA's Scientific and Technological Program Reviews, and Vice-President Quayle's Space Policy Advisory Council. He was Chairman of the NASA Advisory Council Task Force for the Shuttle-Mir rendezvous and docking missions, and was Co-Chairman of the Stafford-Covey Space Shuttle Return to Flight task force following the Shuttle "Columbia" accident in 2003.

As of January 2017, General Stafford serves as the Chairman of the NASA Advisory Task Force on ISS (International Space Station) Operational Readiness.

Chairwoman HORN. Thank you, General Stafford. Mr. Young, you're recognized.

TESTIMONY OF A. THOMAS YOUNG, FORMER DIRECTOR OF NASA GODDARD SPACE FLIGHT CENTER; FORMER PRESIDENT AND CHIEF OPERATING OFFICER, MARTIN MARIETTA CORP.

Mr. YOUNG. Chairwoman Horn, Ranking Member Babin, and Committee Members, and Committee Chairwoman Johnson, and Ranking Member Lucas, I'm pleased to have the opportunity to present my views as to the critical actions necessary to maximize the probability of success of the Mars-Moon human exploration program.

Mars human exploration, with humans to the Moon as preparation, is one of, and perhaps the most challenging, exciting, and potentially rewarding exploration endeavors ever undertaken. The challenges and risk cannot be overstated, nor can the excitement and anticipated extraordinary rewards. It is a bold and achievable endeavor that the United States should pursue. Business as usual will not be adequate to successfully implement the Mars-Moon program. The best of the best will be required. Extraordinary actions will be necessary, requiring that the program have high national priority.

NASA has exceptional Moon and Mars experience, with sophisticated robots at the Moon and Mars, and humans on the surface of the Moon. No one else, domestic or international, has this breadth and depth of exploration experience and capabilities. The challenges of the Moon-Mars program are such that the leadership capabilities of NASA must be augmented. Additional senior experienced leadership from other government organizations, industry, and academia will be needed, as was the case for Apollo.

Strengthening the NASA workforce will also be necessary. Half a century has passed since Apollo, making that experience less relevant. A workforce experienced in the development and execution of large, complex space projects will be required. The International Space Station, Orion, SLS, and the Mars Robotic program have contributed significantly to workforce development. I believe the most important role for the lunar phase is additional workforce experience. Mercury, Gemini, and Saturn V clearly were important contributors to workforce development for Apollo.

The United States aerospace industry has implementation capabilities that are second to none. Utilizing the implementation capabilities of industry, in partnership with the breadth of NASA experience, will be critical to achieving program success. More specifically, the full capability of NASA and industry will be required. Management and contracted experiments must be excluded from the Mars-Moon program. Implementation will be at the limitation of our capability, without the additional complications of management and contracted experiments. A clear, unambiguous goal is required. Is the lunar part of the program to support success at Mars, or is it to achieve sustained lunar presence? Does the Mars part of the program have specific objectives, such as a Mars orbital mission, followed by boots on the ground, or is it a long-range ob-

jective? Answers to these questions will have a profound impact on schedule, cost, and a reasonable timeline for humans to Mars.

A clear, unambiguous goal must be followed by a detailed plan that is consistent with the goal, and developed by the Mars-Moon program leadership. A detailed plan is the glue that integrates the vast array of Mars-Moon participants into the incredible team necessary to implement the Mars-Moon program. Additionally, a detailed plan is necessary to rally support, develop a credible budget, and obtain program then budget approval. Obviously, a budget is required. To be credible, the budget must fund the most probable cost of the program. My understanding of NASA policy is that the most probable cost is defined as a 70/30 cost estimate.

The budget should be phased by fiscal year, consistent with the work plan associated with the detailed plan discussed earlier. This will result in a budget profile that is a bell shape, with higher fiscal year funding required in years for development, manufacturing, integration, and testing. Flat budgets, with a relatively equal funding each fiscal year, is the least efficient program management approach. A flat budget approach can result in years of scheduling delay, and potentially doubling the project cost. Obviously, a flat budget should be avoided.

Today NASA's human space flight program plate is full. It includes ISS, commercial cargo, commercial crew, low Earth orbit commercialization, the new commercial space paradigm, et cetera. All are demanding activities. SLS, Orion, and Gateway are challenging elements of the human space flight endeavor. In my opinion, the inclusion of the Mars-Moon program makes the portfolio of human space flight activities unachievable with an acceptable probability of success. Priorities, and most likely the termination of some activities, will be clearly required.

The Mars-Moon program is clearly the most challenging and difficult civil space program ever undertaken. Success will depend upon the recognition of the challenges, difficulty, and risk. Success will depend upon the implementation of extraordinary actions necessary to have a sufficiently high probability of success. In summary, the actions include: NASA leadership augmentation, strengthening NASA workforce, full utilization of NASA and industry capabilities, avoiding management and contracting experiments, a clear and unambiguous goal, a detailed plan, a budget consistent with the most probable cost estimate, prioritization of human space flight activities, and elimination of current human space flight activities necessary to assure that required resources are available for implementation of the Mars-Moon program.

The Mars-Moon program, while bold, is achievable. Extraordinary actions will be required to assure success. A business-as-usual approach will most likely end in failure. The absolute best of NASA, industry, academia, and our international partners is required. Thank you.

[The prepared statement of Mr. Young follows:]

TESTIMONY TO THE

COMMITTEE ON SCIENCE AND TECHNOLOGY

SUBCOMMITTEE ON SPACE AND AERONAUTICS

NOVEMBER 13, 2019

A. THOMAS YOUNG

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less relevant. A workforce experienced in the development and execution of large, complex space projects will be required. The International Space Station (ISS), Orion, SLS, and the Mars robotic program have contributed significantly to workforce development. I believe the most important role for the lunar phase is additional workforce experience. Mercury, Gemini, and Saturn V clearly were important contributors to workforce development for Apollo.

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Management and contracting experiments must be excluded from the Mars-Moon program. Implementation will be at the limitation of our capability without the additional complications of management and contracting experiments.

A clear, unambiguous goal is required. Is the lunar part of the program to support success at Mars or is it to achieve sustained lunar presence? Does the Mars part of the program have specific objectives such as a Mars orbital mission followed by "boots on the ground," or is it a long-range objective? Answers to these questions will have a profound impact on schedule, cost and a reasonable timeline for humans to Mars.

A clear, unambiguous goal must be followed by a detailed plan that is consistent with the goal and developed by the Mars-Moon program leadership. A detailed plan is the "glue" that integrates the vast array of Mars-Moon participants into the incredible team necessary to implement the Mars-Moon program. Additionally, a detailed plan is necessary to rally support, develop a credible budget, and obtain program and budget approval.

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Today, NASA's human space flight "plate" is full. ISS, commercial cargo, commercial crew, Low Earth Orbit commercialization, the new commercial space paradigm, etc. are all demanding activities. SLS, Orion, and Gateway are

challenging elements of the human space flight endeavor. In my opinion, the inclusion of the Mars-Moon program makes the portfolio of human space flight activities unachievable with an acceptable probability of success. Priorities and most likely the termination of some activities will clearly be necessary.

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- NASA Leadership augmentation
- Strengthening NASA workforce
- Full utilization of NASA and industry capabilities
- Avoiding management and contracting experiments
- A clear and unambiguous goal
- A detailed plan
- A budget consistent with the most probable cost estimate
- Prioritization of human space flight activities

- Elimination of current human space flight activities necessary to assure the required resources are available for implementation of the Mars-Moon program.

The Mars-Moon program, while bold, is achievable. Extraordinary actions will be required to assure success. A "business as usual" approach will most likely end in failure. The absolute best of NASA, industry, academia and our international partners is required.

Thank you.

A. Thomas Young

A. Thomas Young is the former Director of NASA's Goddard Space Flight Center, President and COO of Martin Marietta and Chairman of SAIC. He retired from Lockheed Martin in July, 1995 and the SAIC Board in 2013. Mr. Young is involved in various advisory and review activities associated with the U.S. Space Program.

Mr. Young began his career with NASA at the Langley Research Center in 1961. He was a member of the Lunar Orbiter Project Team and was Mission Director for Project Viking, which resulted in the successful landing of two spacecraft on the surface of Mars. He became Director of the Planetary Program at NASA Headquarters in 1976 and was appointed Deputy Director of the Ames Research Center in 1978. Mr. Young was Director of the Goddard Space Flight Center from 1979 to 1982. He joined the Martin Marietta Corporation in 1982 and was subsequently President of Baltimore Aerospace and the Electronics and Missiles Group. Mr. Young was President and COO of Martin Marietta from 1990 to 1995.

Mr. Young is a Honorary Fellow of the American Institute of Aeronautics and Astronautics, a Fellow of the American Astronautical Society, a Fellow of the Royal Astronautical Society and a Fellow of the International Academy of Astronautics. He is a member of the National Academy of Engineering and the University of Virginia Raven Society. Mr. Young is a former member of the NASA Advisory Council.

Mr. Young earned a bachelor of aeronautical engineering degree and a bachelor of mechanical engineering degree in 1961 from the University of Virginia. In 1972 he received a masters of management degree from MIT which he attended as a Sloan Fellow. He also holds a honorary doctor of science degree from Salisbury University.

Chairwoman HORN. Thank you, Mr. Young. The Chair now recognizes herself for 5 minutes.

Again, thank you both for your breadth and depth of experience and expertise. I think it's clear that we are facing some important challenges in addressing both how we set the program up, from a standpoint of authorization, but also funding. And so I'd like to start, Mr. Young, with a couple of your comments, and looking at the current program that NASA is undertaking. You touched on a couple of these things, but I'd like to follow up. What would it take, at this point, under the current program, to enable a lunar landing by 2024? Is that, at this point, something that you think we can achieve in that timeframe?

Mr. YOUNG. Clearly the budget, which you touched on, but the items that I mentioned—one is it's going to take some extraordinary leadership, and NASA has exceptional capability today, but not enough, so the NASA leadership needs to be augmented somewhat in the manner that Apollo was done. I recall on Apollo General Sam Foltz, a four-star Air Force general, was brought over to the—George Miller from industry was brought over. Bellcom was established by AT&T at Bell Labs to support NASA headquarters, and they actually ended up having 500 people involved in that activity, so staffing is a critical item.

I guess the other item—I went through a list, but the other item is—the plate is really full today, and if—again, if we compare us with the Apollo era, you know, it was basically Apollo, which were following Mercury and Gemini. I mean, today the array of things that NASA is charged with doing is overwhelming. And I personally think that the leadership is going to have to, number one, prioritize, but, number three, is probably to eliminate some of the things that are currently being done that will interrupt having any opportunity of 2024, or I would say even 2028, about making those kinds of decisions.

Chairwoman HORN. Thank you very much. And, General Stafford, I want to follow up. I think it's remarkable that the work you did in 1991 is still so instructive and informative today, and the time and effort you put into that. So, in that report, you talked about accomplishing necessary system demonstrations and preparations on the Moon prior to attempting a challenging Mars mission. Do you still believe that a stepping-stone approach is the best pathway to send humans to the Moon?

Lt. Gen. STAFFORD. Absolutely. This was looked at in-depth, and, you know, we looked at ways at first we could just go direct to Mars, and the more we looked at it, and this was a whole group of all types of input, you could do a series of things on the Moon that would be similar to Mars. In fact, you could use Martian hardware on the Moon. Moon has got one-sixth, Mars has 38 percent of Earth's gravity. And we actually could simulate it up to certain days, and all this, so there's so many things to do, and work out the unknowns. And so the answer is yes, it's go to the Moon first, and then Mars. You wouldn't launch from the Moon. You'd launch from the Earth to go to Mars, but you could work out so many of the problems.

Chairwoman HORN. Thank you. And, following on that, General Stafford, you mentioned, and this is also in your report, the essen-

tial need for a heavy lift vehicle. Can you speak to how a heavy lift vehicle—why it's important, and how it affects the systems and decisions, such as the human landing system?

Lt. Gen. STAFFORD. Right. For the Members of the Committee, just to review, goes back to Tsiolkovsky's Law, a simple three-term equation. Say on Gemini, it weighed 315,000 pounds at ignition. I went into orbit, and that Gemini had a little less than 8,000 pounds. I had 2 percent of the mass of ignition that I was in orbit. Now, on Apollo, because we had hydrogen in the upper stages, it was more efficient. It was later on in technology. But when I went to the Moon, I had 6.4 million pounds at ignition, into orbit with 300,000 pounds, which a large part was hydrogen to take—and oxygen to take us out there. But I had 4.8 percent in low Earth orbit of what I ignited with. And then we ignited after 1-1/2 revolutions around the Earth to go on a trans-lunar injection, which picked up 11,000 feet per second. When that shut off, then I had a useful payload of 100,000 pounds, the lunar module and the commanding service module. That was 1.6 percent of what I started with. So just for weight alone, if you don't have a big booster, you're not going to make it.

But also so important, that's often left out besides just weight is the size. You need a big payload shroud to carry the rovers, the habitats, the infrastructure. You have to have a big shroud, which leads you to a big, wide-diameter booster. If you don't have it, you're not going to make it.

Chairwoman HORN. Thank you very much, General. My time has expired. I recognize Mr. Babin for 5 minutes.

Mr. BABIN. Ma'am, thank you. General Stafford, previous Administrations have argued that we should not return to the Moon because we've been there before. Would you feel more comfortable conducting a mission to the Moon to test systems for an eventual Mars mission, or would you prefer to skip directly to a Mars mission, and is it prudent to first test capabilities days away, when you're on the Moon, before attempting a mission to Mars, which would be months or years away from Earth, in case problems arise?

Lt. Gen. STAFFORD. Congressman Babin, as the saying goes, I may be a little dumb, but I'm not stupid. Now, we went through this in great detail, and the Moon is only 3 days away——

Mr. BABIN. Yes, sir.

Lt Gen. STAFFORD [continuing]. And if you have something—there's a way, possibly, to get back—other ones to help you, and you're in direct communications. For example, we said to condition to the—we'd have a small space station that would be there for the period of time it would take to go to the Moon a chemical rocket at the right time of the year. You can't go there every year because there's a 15-year period of energy——

Mr. BABIN. Right.

Lt Gen. STAFFORD [continuing]. Sinusoid, and you can only launch every 26 months, but right now the lowest point, and the best energy, was in 2016, and so the next time is 15 years later——

Mr. BABIN. Yes, sir.

Lt. Gen. STAFFORD. —2031, and the worst time is 2024.

Mr. BABIN. Well said.

Lt. Gen. STAFFORD. Anyway, go for, say, 260 days or so in a small, like, station around the Moon. This is one place where the gateway might be feasible. There's a lot of things I think is not feasible about it. And then we'd land, and then, to simulate 38 percent gravity versus 16 percent, we'd have just weights on the shoulders, just like football players train with weights, that would bring your weight from 16 percent to 38, so that would tell you how mobility—and this is just a simple thing. We would——

Mr. BABIN. Yes, sir.

Lt Gen. STAFFORD [continuing]. Do other things about that. So we think it's imperative. And also you have to learn how to recycle your oxygen and recycle the water. We're doing a lot of this on the Space Station, but we need to get the efficiency higher.

Mr. BABIN. OK. Yes, sir, thank you very much. And, Mr. Young, your testimony states that management and contracting experiments must be excluded from the Mars-Moon program. Can you expand on that a little, and is the next step broad agency announcement for human landing systems an experiment that would introduce unnecessary risk to the program?

Mr. YOUNG. Co-pilots and pilots are supposed to guide each other here. NASA has extraordinary capability that should be fully utilized and executed in the program. That's kind of the number one premise. And industry has extraordinary capability in implementation, which should be utilized. So I'm not a fan of an acquisition process that basically is training industry to do the job that NASA has historically done in favor of an acquisition process that makes maximum use of both capabilities.

As an example, a management experiment, in my view, would be to buy seats for crews to fly to the surface of the Moon. I personally think that these should be government-acquired assets under the leadership and direction of NASA, with industry having a full capability implementation. I think commercial cargo, if I went back to that, was an experiment that was worth doing, and in my view, if it didn't work out, it failed soft. Commercial crew, in my example, is not the kind of concept that I would propose or support that we implement for the lunar program.

Mr. BABIN. Yes, sir.

Mr. YOUNG. So I'm working off maximize probability of success, utilize all the capabilities you have to do that.

Mr. BABIN. Thank you. Real quickly, General Stafford's testimony states, "the leadership capability at NASA must be augmented at headquarters and applicable centers." Mr. Young's testimony states, "the challenges of the Moon-Mars program are such that the leadership capabilities of NASA must be augmented." What exactly do you gentlemen mean by that, and would you elaborate on that, and how the administration can improve its leadership and augmentation?

Lt. Gen. STAFFORD. Mr. Babin, I'll start. When we pulled in Mr. Webb, and the administration pulled in the best talent available, and that was General Sam Phillips, and he had managed the B–52. We built 740-some B–52s, and he's the one that put the 1,000 minutemen in the ground, so he had tremendous experience. And I know of nobody that has the experience of General Sam Phillips today. And we were fortunate, too, down at Marshal Space Flight

Center. We had Dr. Von Braun—his team had designed, developed, and produced 6,000 V–2 rockets in World War II, and then started the Redstone Rocket here in the States, our first ballistic missile.

I don't know of any talent like that available, so it's going to be tough to augment. We did have Bellcom, as Mr. Young mentioned, came from Bell Laboratories. It was Bell Laboratories that started the idea of systems engineering. And so they had, I think, up to 500 people—Tom?

Mr. YOUNG. Yes.

Lt. Gen. STAFFORD. Here at headquarters that would help them. So I'll——

Mr. BABIN. Yes, sir.

Lt Gen. STAFFORD [continuing]. Turn it over to Mr. Young.

Mr. YOUNG. I could add to what General Stafford has said. First thing I want to make clear is that this is not a criticism of the current NASA. It's a recognition that a Mars human program is probably the most challenging thing we have ever done as a civilization. I mean, it, you know, we just can't underestimate what a challenge it is, I think achievable challenge. Even returning to the Moon, you know, will be a challenge. So what that says is we've just absolutely got to have the best that the country has available. And what that says is that we need to augment the current NASA capability, like we did in Apollo. And if we don't, then we're probably embarking upon something that we should not embark upon.

Mr. BABIN. Thank you very much. I'm way over, sorry.

Chairwoman HORN. That's OK. Thank you very much, and Mr. Babin, thank you. The Chair recognizes Chairwoman Johnson for 5 minutes.

Chairwoman JOHNSON. Thank you very much. Mr. Young, we're here today to get your perspective on the most effective and sustainable path forward for our Nation's human exploration program, and you have commented some on that, but I'd like you to tell me your thoughts on what should be our exploration goal, and the timeline. Give us your perspective.

Mr. YOUNG. Good question, thank you. My personal belief is that the most compelling opportunity is humans to Mars. I also, as I just mentioned, respect and understand how challenging that is, and I believe that we certainly can maximize the probability of that mission by lunar activities. So I'm an advocate of the lunar part of the program being preparatory for the Mars part. I do have a worry that it's possible that we could get bogged down at the Moon, so I think we really need to clearly define what it would be. So, if I were personally writing the goal that you talked about, it would it would be boots on the ground at Mars, and that we should implement those things that are necessary, like the lunar program, to maximize probability of success, and also recognize that we do need intermediate milestones where we can demonstrate success as we're going on.

I'm going to cheat with time, but just to add, I've thought a bit about, you know, Apollo had the advantage of an international competition with the Soviet Union, so what drives us to do a similar kind of a thing for Mars? And there are a lot of reasons—science, geopolitical. My personal belief is that today we live in a very challenging, complicated world, and it is possible for a young

generation to be discouraged, and even depressed, by some of the—and I don't see that changing. To have an objective of something like humans to Mars, seems to me, is the inspiration, and the beacon, and the bright light, and it's a way to tell our generation, and your all's generation, to tell the future generations there's a lot of opportunity that's out there, you know, and don't be turned off by just the fact there are an awful lot of challenges, because, you know, humans to Mars is just an incredible endeavor.

And I can go one step further. I can envision, every day, the crew, to keep them seen, communicating with us here on Earth, telling us what's going on, and that, in itself, you know, kind of allowing all of us to participate in the trip to Mars. Thank you.

Chairwoman JOHNSON. Thank you. General Stafford, what lessons do we need to take away from the Gemini and Apollo programs that we consider—structing an effective Moon-Mars program for sustainability and success? As we think about where we are today with our human exploration program, what, if anything, do we need to change?

Lt. Gen. STAFFORD. Well, Chairwoman Johnson, it's a very good point. As I sit in this room and look around at the Chairmen, and I see pictures of Chairman Teague from Texas, one of the great Chairmen, and I think I testified for him 3 or 4 times, and he said, what should we do to keep going? I said, one thing, Mr. Chairman, is to have consistency, and that's what we had in both Gemini and Apollo, we had consistency. And we need consistency in funding, resources, support, legislative, and all this to keep us going.

We have to have that, because, as pointed out, President Bush started the space exploration issue, then the next Administration under Clinton came in, he basically terminated it, and exploration languished for 8 years, and then we started back up after about 3 years into George W. Bush's Administration. And we started rebuilding our systems engineering and sustainment, and it went up, and then his 8 years were up, and then the budget was cut right away, and down, and—the Constellation program that had started and it was building a big booster out of parts of the Shuttle, part of the Saturn, but it went down. And so you have to have consistency. That's the main thing. And also realism, like in one of your opening statements you said you have to learn from the past, like I said from what George Santayana said. You're going to repeat the lessons of history if you don't learn from them.

Chairwoman JOHNSON. Thank you very much. My time's expired.

Chairwoman HORN. Thank you, Madam Chair. The Chair recognizes Ranking Member Lucas for 5 minutes.

Mr. LUCAS. Thank you, Madam Chair, and I want to continue down, I think, essentially the same path a number of my colleagues are going. NASA's requiring the human landing system to launch aboard commercial launch vehicles, rather than the more capable SLS. That means more launches, more on-orbit rendezvous, more on-orbit assembly, fails to leverage the investments that we've made in SLS. Now, General Stafford, you conducted some of the first on orbit rendezvous during the Gemini program, and flew aboard Apollo 10, which conducted the dress rehearsal of Apollo 11, and chaired the Advisory Committee in the 1990s, so safety is an issue with you. Could you touch for a moment, if we're going to go

with that smaller system for doing things, what do multiple launches and multiple on-orbit rendezvous affect safety and risk postures for the lunar landers?

Lt. Gen. STAFFORD. Well, Mr. Lucas, that's a very good question, and the mission I did to encompass the whole thing was one launch. And I reviewed the material that Mr. Cooke testified for this Committee I think a little over a month or so ago, and outlined it, and there's eight launches required under the present architecture. Only one are the big ones, the rest are small ones. And the probability of success, as he outlined, and I cannot disagree with it, was only 50 percent. And I certainly would not want to start that.

In Apollo, we had a goal of crew safety of 999, and mission success of .90. And if you review what we did on Apollo, he first mission was just on a small Saturn Earth orbit, but on the big Saturn we had 10 missions, and nine of those were successful. We had Apollo 13. It was a success to bring the crew back. We hit the three times of bringing the crew back, but the mission failed to make the third lunar landing, so we were right there are .9. But with eight launches, I'll have to go with Mr. Cook, your probably of success goes down to about 50 percent.

Mr. LUCAS. Oh my. Mr. Young, to continue down the path of your comments, and your testimony, listed, of course, a number of recommendations to ensure that NASA plans move forward successfully. One of those recommendations is to prioritize human space flight activities. Could you discuss for a moment, if NASA does not get additional funding, and the ISS operations are extended to 2033, I think I know the answer, but for one more time, will this delay deep space exploration?

Mr. YOUNG. Absolutely it will delay it. It will delay it significantly also, yes.

Mr. LUCAS. General Stafford, on Apollo 10 you flew closer to the Moon than anyone ever before. Of course, this gave you a unique, up-close perspective of the Moon's geological features, the craters, the boulders, and this informed the final landing, and provided scientists with important information. Will a return to the Moon teach us valuable information about the Moon and the Earth?

Lt. Gen. STAFFORD. Mr. Lucas, absolutely, and in the book here we had, you know, our charter was to give two or more architectures, and the technology priorities. In other words, how do we go back to the moon? And about 4 months into the year's effort we had, it became obvious to us we have to say, why should we go back to the Moon? And so that is included in this book. And what we would learn from it is really a tremendous amount of knowledge, and what you can do from it is unbelievable. And it takes too long to go into the details. They're all inside the book there, sir. But, yes, there's reasons to go back.

Mr. LUCAS. One last question, General. I know it's been a day or two since you did it, but that must have been a tremendous view out the window of that lander.

Lt. Gen. STAFFORD. Well, the lander was a unique vehicle, Mr. Lucas. It was a very flimsy vehicle. Unpressurized, you could take your thumb and push hard between the frames, and the skin would bow out. And then we only flew at five pounds per square inch pure

oxygen, and when you did that, you see the rectangular hatch in front of you where you crawled it, it would bow out. It was not meant for, you know, air-type operations. It was made out of very thin material, and it worked one time, but it did the job, and it did the job real well. We six successful landings. We brought back 842 pounds of rock and material from the Moon, and from that we have certainly learned a lot.

Mr. LUCAS. Thank you, General. Yield back the balance of my time.

Chairwoman HORN. Thank you, Ranking Member Lucas. The Chair recognizes Mr. Perlmutter for 5 minutes. And he's going to pull out his—yes, there it is. There's the bumper sticker. I knew it was coming.

Mr. PERLMUTTER. Gentlemen, thank you for your testimony today. I kind of feel intimidated by the two of you being here, and sharing with us your thoughts and your knowledge about all of this. And, you know, clearly, General, you talk about consistency, and from Administration to Administration it kind of varies and changes. And, quite frankly, I think it's our responsibility, as Members of Congress who are here, and this institution goes on and on and on, for us to set these unambiguous goals with an international project such as this, because it's huge, and it's going to take a long time to really get the pieces. It's going to have to have a budget that is worthy of the task that you're undertaking.

So Mr. Young has seen my bumper sticker before, and the, you know, we talked about repeating history, but the other side of that is—the fact is we did do it with Apollo, and Gemini, and Mercury, when we didn't have nearly the capabilities that we have now. And so my bumper sticker says 2033, and the small print you can't see, this is Mars over here, says "We can do this." We can do this, if we have consistency, a purpose, an unambiguous goal, and Democrats and Republicans, together with the people of the country and the world, say, we're going to do it. We will do it.

So my question to you—I'll start with you, Mr. Young, and I really—your testimony, both of you, again, re-energizes me to go just be persistent as hell about doing this. So you talked about the need for kind of public involvement in this. How do you think NASA's doing in engaging the public? Can they do more? Should there be more done?

Mr. YOUNG. That's kind of a hard question to answer. My observation is that Administrator Bridenstine has gone above and beyond in interacting with the public, giving, you know, speeches, and advocating strongly for, you know, for the program. So, in that regard, I would say, you know, a positive. So I guess that's kind of the limit of my observation, and I'm on the outside looking in, but I do think the advocacy, you know, has been quite positive.

I think that the early—making some progress on some of the items that I identified in my testimony have not been, you know, as actively, you know, engaged with, and I recognize the difficulty. I am struck by the fact that the Vice President's speech was 6 months ago, and I guess Tom Stafford would remind me again there's nothing more useless than runway behind you, and altitude above you, and it's also time behind you too. So I think we really do have to, you know, function with a high degree of urgency. I'm

an advocate for mission success, but I'm an advocate to balance that with urgency, and—so I guess—I'm rambling, but my general comment is I think that the support for the program has been strong, but a lot of the actions that I think that are necessary are yet pending.

Mr. PERLMUTTER. Any thoughts, General?

Lt. Gen. STAFFORD. Well, I agree with Mr. Young that Mr. Bridenstine has been out there really, you know, putting forth the rationale, the reasons, for the exploration, but we still have a lot of actions to go. And when I see this one architecture, I don't know how it was put together to have eight launches to do one landing. That is concerns me a great deal, sir.

Mr. PERLMUTTER. I think, again, from just sitting up here, and being a Member of Congress, I mean, our responsibility is to provide funding so that the agency, as the lead of this—and I think it's going to be international in scope, and public-private. It's going to require all of those things to maximize the success. But I'd love to have you two go with me, and I'll grab, you know, somebody over there, Dr. Babin, and we'll go from appropriator to appropriator to talk about this being the kind of thing that can bring a lot of people together, because it's so aspirational, if you will. And, with that, I'm going to yield back to the Chair, because I could go on forever on this thing.

Lt. Gen. STAFFORD. May I add one thing to that?

Chairwoman HORN. Of course.

Lt. Gen. STAFFORD. You know, sir, over the years I've had so many people come up to me, said, the reason I went to college, I saw you fly—and your group fly Gemini, and Apollo, and I saw what you did, I wanted to be part of it, and——

Mr. PERLMUTTER. That's right.

Lt Gen. STAFFORD [continuing]. Or at least support part of it. I mean, there's literally hundreds of people said they went to college, and studied, and all this.

Chairwoman HORN. Absolutely. Thank you very much. Thank you, Mr. Perlmutter, and thank you, General. The Chair recognizes Mr. Posey for 5 minutes.

Mr. POSEY. Thank you, Madam Chair, for holding this hearing on deep space exploration that involves going back to the Moon, and then to Mars, and for accommodating these two great, awesome witnesses that we have here to share with us today. To achieve the ambitious deadline of putting boots on the Moon in 2024, I think that we all agree that we all must do everything we can to ensure that there's sufficient funding to do that. I think that's where the buck stops, will we have the money to do that? And I agree with our esteemed witnesses that both the Administration and Congress must continue to fully fund the necessary assets, such as Space Launch System, Orion crew exploration vehicle, exploration ground systems, Mobile Launcher II, and the Lunar Orbital Platform we refer to as the Gateway to ensure that we stay on track to meet those targeted launch dates.

In addition to fully funding the critical space assets, I think we need to ensure safeguards are in place to protect the astronauts from radiation in deep space, as well as the other hazards that are

inherent to such missions. And, with NASA's strong leadership, and a firm commitment from Congress, I think we can do that.

The questions, General Stafford and Mr. Young, 10 years ago the National Academy of Science conducted a review of risk posed by radiation exposure during crewed deep space exploration. They evaluated shielding options, mitigation techniques, and recommended strategies for future missions. Do you think the state of science has changed since the last assessment, and, if so, would it be helpful to revisit the subject and seek further guidance or updates?

Lt. Gen. STAFFORD. Well, even though I'm not a medical doctor, let me tell you the information here at the sea level—our latitude. We receive approximately 2.—probably six millisieverts of radiation a year. In the Space Station, or in low Earth orbit, below the Van Allen Belts, you get about 6/10 of a millisieverts a day. So, in other words, in 10 days, say on board the Space Station, you get equal to 1 year on the ground.

Mr. POSEY. Wow.

Lt. Gen. STAFFORD. Now, for the 24 of us that flew beyond the Van Allen Belts, once you get out there, you get about 2.6 millisieverts a day, so in 2-1/4 days, you get equivalent to a year on the ground. Now, from the study we did, we had the Department of Energy come in to us, and medical doctors from radiation expertise, and they used the term 16 grams per centimeter cubed. Well, I think—I'm Oklahoman, different—inches per, you know, pound, so it equates to about 1 foot of water would protect you from all solar radiation, and you could use that 1 foot of water in, say, an inflatable, and recycle it. And you have to recycle the water. Just like you use 2.2 pounds of oxygen a day, you need about 6 pounds of water a day. That water would be enough to shield you very well from the solar radiation. Now, cosmic radiation is a whole different ballgame, but that's not near as prevalent.

Mr. POSEY. OK. Mr. Young——

Mr. YOUNG. I don't have anything to add.

Mr. POSEY. Tough to top that one for sure. General Stafford, as someone who's actually flown a lunar landing module during Apollo, and I had the honor and pleasure to work as an inspector on the third stage of your rocket back in the day, you have unique insight as to what we need to be considering now as we begin to build a lunar landing module for Artemis. I wonder if you could identify the key lessons from the development of the Apollo lunar module that we need to incorporate into the current architecture? You know, may it be key safety testing, oversight, you know, requirements that are necessary for these complex missions that might stick out in your mind.

Lt. Gen. STAFFORD. Well, you hit on a lot of them right there, as far as inspection oversight, but you want to keep things as simple as possible, even though it's a very complex subject to work with. And you can't let anything sneak up on you. And you have to have great quality in everything you do.

As I pointed out, I don't—in my own opinion, and also what Mr. Cook said, that—I don't think that starting with eight launches to put a series of four small things together is going to be the right way to go.

Mr. POSEY. OK.

Lt. Gen. STAFFORD. Let's take an example. The Space Station, it weighs about 900,000 pounds now, but yet nearly 30 percent of that weight is in the coupling devices to keep it together.

Mr. POSEY. OK.

Lt. Gen. STAFFORD. So you want to keep the things as simple as possible within the units. And if you have these four units, each one has to have an electrical power system, a reaction control system, a docking mechanism on them, all this, and a propulsion too. So versus just an Apollo, in the lunar module we had just one guidance system. That took care of the whole thing.

Mr. POSEY. Yes.

Lt. Gen. STAFFORD. One RCS system.

Mr. POSEY. Well, that was a miracle, General, you know, almost a miracle. Thank you, Madam Chair. I yield back.

Chairwoman HORN. Thank you, Mr. Posey. The Chair recognizes Mr. Olson.

Mr. OLSON. I thank the Chair, and welcome Mr. Young and General Stafford. General Stafford, as you know, on Monday our Nation celebrated Veterans Day, and you are an amazing veteran. I want to thank you first for your amazing service to our country, and especially 507 hours and 43 minutes in space on Gemini 6, Gemini 9, Apollo-Soyuz, and, as been mentioned over and over, Apollo 10. You all did everything to land on the Moon except for actually put the limb down. Got down there, I talked to Gene Cernan, he thought about shooting the approach, but guess what, the guys back in Florida did not properly fuel the LEM to have a landing come back, thank you. I know it's tough going out there because on the way out you had to catch something floating through the command module. I'll leave that to yourself to explain what happened.

Also, General Stafford you all mentioned the power to motivate our young people, seeing human beings in space. I see it all the time back home. I grew up right in the shadow of the Johnson Space Center. I show kids, this is not to slam on the missions, but I show kids the Mars Rovers, which are great. We learn so much about Mars with those Mars Rovers. Then I show them Bruce McCandless, out there with the jetpack. Bruce McCandless, Rocket Man. Everybody wants to be Bruce McCandless. And so we can't put a value on that persona, we have to tap into that to go forward.

You've chaired the ISS Advisory Committee now for the past couple years, and my question is, how can the ISS help us out going back to the Moon and going to Mars? And we're trying to extend that, how to make sure that happens? Also, going to the Moon, that was all us, all America. International Space Station, that's international. That great arm, that came from Canada. Russia has told our guys up there, cargo vehicles, manned vehicles, Soyuz vehicles, how about some international help going back to the Moon, and possibly to Mars?

Lt. Gen. STAFFORD. Well, thank you very much, sir. Yes, I think international help can be there, but they also have to be on time.

Mr. OLSON. And pay.

Lt. Gen. STAFFORD. And pay. The one thing—the Space Station—I'm very proud of what they've done. They've helped solve some of

the—put us on the way of solving the problems. As I mentioned, you know, 2 pounds of air—2.2 pounds of air you use every day, and about 6 pounds of water, we are recycling the air, recycling the—we've learned how to do that now on the Space Station. We still have to increase the efficiency to get—but the Space Station also, we've learned now this—called the ARED, Astronaut Exercise Reactive Devices, like pumping iron in space. And with the proper diet, and also some pharmaceuticals, you can keep the muscle mass up, the red blood cells up, and everything else. So the Space Station has put us way up here as far as knowledge for long duration missions that can take us to Mars.

Mr. OLSON. And Gene Cernan, your crewmate there on Apollo 10, echoed your comments about the best place to train for going to Mars is the Moon. As you mentioned, Moon is about 1/3 of Earth's gravity. Also, we found out, since the Apollo missions, guess what's all over the Moon? Water. OK, so comment about how much going to the Moon, is that an important step to going back toward Mars? What can we learn by going back to the Moon that helps us get to Mars as quickly as possible, and safely as possible?

Lt. Gen. STAFFORD. Well, it'll teach us on first working in deep space beyond the low Earth orbit. And, from that, again, the equipment, and how long, you know, the reliability of the equipment, what we need to do, and—it's going to be a whole series in which—I've listed here, sir. It'll take a while——

Mr. OLSON. Yes, the bible.

Lt Gen. STAFFORD [continuing]. To go into it. Definitely. Trying to go to Mars, not going to the Moon, is really a no brainer not to do it.

Mr. OLSON. Question, Mr. Young. I'm concerned about the SLS for one reason. As Mr. Stafford mentioned, the vehicle he went to the Moon on was the Saturn V rocket, designed for one thing, take three people from here to the Moon and back, with the lunar module, and later missions with the lunar rover. OK, we built this rocket for one mission. The SLS is designed to go to deep space, so any concerns about just having a generic mission, as opposed to build this rocket, hit this exact mission? Adapting the SLS to going to Mars, maybe, which we're hoping it can do, but——

Mr. YOUNG. My observation is that SLS, you know, does have the capability to go to, you know, to support a deep space——

Mr. OLSON. Better.

Mr. YOUNG [continuing]. Such as Europa, but I think that, you know, my observation is that the focus of SLS has been a heavy-lift capability aimed primarily at being able to support a lunar and a Mars human mission, and in addition to that, it also has a capability which, my guess is the Saturn V would've had that capability also, to do missions that require heavy-lift capability to minimize flight time, which is the Europa situation. So my observation, and I appreciate Tom's comment, is that I don't think that SLS has been compromised from its primary use of humans to the Moon and Mars.

Mr. OLSON. Thank you. General Stafford?

Lt. Gen. STAFFORD. Let me add that, you know, in the 2010 NASA authorizations say, start with a minimum, and the word is minimum, of 70 metric tons, to grow to a minimum of 130 metric

tons. Now, 130 metric tons is just nearly what we had on the Saturn V. And you're sort of an odd duck sir, but it does have the capability to increase even beyond 130 metric tons——

Mr. OLSON. Right.

Lt Gen. STAFFORD [continuing]. But you have to get that enhanced upper stage built, and go on it.

Mr. OLSON. Ms. Chairwoman, one final question for Mr. Stafford, because you went to the Naval Academy, and then joined the Air Force, so basically your experience there as a midshipman—as you know, in the next four weeks there's this big football game between Army and Navy. So, in your humble opinion, who's going to win that football game? Any idea?

Lt. Gen. STAFFORD. Sir, I just could not forecast on that.

Mr. OLSON. I can for you. Go Navy, beat Army.

Chairwoman HORN. General, he likes to stir up trouble around football games, you should probably know that. Although he has been wrong already this year. Thank you very much. Gentlemen, I think I have a few more questions, if you'll indulge us a little bit longer. I think—I want to express our gratitude for your wisdom, and candor, and all of the work that you've done. This has been incredibly informative, and I don't want to speak on behalf of everyone up here, but I think we've all thoroughly enjoyed it, and found it incredibly helpful. And there were a couple of other points raised in your early testimony that I'd like to follow up on just for a moment.

Mr. Young, when you were talking about how we can streamline and increase the probability of success, you have experience, clearly, in government and industry, you've gone back and forth, and you've been there over attempts to streamline and improve systems, and acquisition. And, in your experience, and in your view, what can Congress do to ensure transparency in the Moon-Mars plan, and an acquisition approach that provides that consistency that we've talked about? Consistency, and also oversight and accountability over the course of a long-term program.

Mr. YOUNG. Few observations. First off, to the consistency, I think that one of the things that maximizes consistency is a high-quality plan, where all people have a strong appreciation of what's really being pursued. And so I think that, you know, that's probably—I guess I should really back up and say an unambiguous clear goal, coupled with a plan that is well-laid out, and is very clear, so that there's no real debate as to what it is that's trying to be accomplished.

Relative to, you know, the overall process of—as I mentioned earlier, I'm a big advocate of using all the resources you have available, and what that really it says to me is that, you know, NASA's an incredible resource, and NASA should not be in the role of just oversight, or just simply standing back and allowing industry to make decisions that, in my view, should be NASA decisions. So I'm a real advocate of utilizing all the capabilities that exist, which says maximum use of NASA, but also recognizing that NASA, you know, is not a manufacturing, you know, is—NASA's not an industry, and we should maximize the use of industry.

We touched on a little bit today, you know, there's a lot of discussion around, you know, commercial, and the new commercial, you

know, paradigm. First off, I think that we should all applaud what the commercial people are doing. You know, I mean, it is terrific. But I think in an endeavor that is so challenging and complicated as this, we really shouldn't confuse it with trying to enhance commercial or not enhance commercial. So my view, in that regard, is all organizations, industrial organizations, that have a capability to contribute, competition should be open for them to compete, and the absolute best should compete, but they're competing to be part of a team led by NASA, and that the procurement should be consistent with that, and NASA really shouldn't be sitting in the back of the room, observing. They should be sitting in the front of the room, leading.

Chairwoman HORN. Thank you very much, Mr. Young. Just a couple more questions. General Stafford, first of all, thank you again. It's truly an honor to hear your experience, and watch the way that your brain works, and being able to go over some of these really complex ideas, and boil it down for us. In your view, what are the top three actions that need to be taken now to structure and implement a Moon-Mars program for sustainability and success?

Lt. Gen. STAFFORD. Chairwoman Horn, number one, has to be an adequate plan, as Mr. Young has pointed out, a real adequate plan. Number two, we have to have the funding to go with it. But number three, we have to have the talent to manage this, and that's the one thing that made Apollo go, we had the talent, and really made Gemini go. In Gemini we did 10 missions in 20 months, which was a real tremendous pace. But when we went to Apollo, it was even faster. The first Apollo flight, I was a backup commander on that. We did, in just 9 short months, five missions, and three of those were to the Moon, and three of them had two spacecraft each on them. And we carried out, in 9 months, and landed on the Moon. Five missions, 9 months and we flew on the giant Saturn V. So you have to have then plan, the resources, but you have to manage it. And this is where Mr. Young pointed out, and I pointed out about how Bellcom came in and did that, and other people.

Chairwoman HORN. Thank you very much. I know I'm a bit over, but my final question is—well, I have many more, but I won't keep you here all day—is—you mentioned that—something that we haven't come back to, we touched on a little bit, General Stafford and Mr. Young, you both mentioned it, perspectives on the role of a Gateway in a Moon to Mars program, and how important is the Gateway, and is there a role for international participation here?

Mr. YOUNG. I think that I do not really see a required role for the Gateway in the lunar program. I do see a role for the Gateway in testing habitat modules, et cetera, for Mars activity. So when I look at this full plate that I talk about, you know, gateway would be one of the areas that, if I were there, that I would look carefully at as to what are the real contributions of it to the overall success of the program. So I guess what I'm saying is that what I know from the outside looking in, gateway—there's not a compelling argument, to me, for the gateway for the lunar program. It is to have capability to test, close to Earth, some of the critical components for the Mars mission, so it would play a role in that regard.

Chairwoman HORN. Thank you. General Stafford?

Lt. Gen. STAFFORD. Well, one thing on the present plan, they have cycling into this orbit called a near rectilinear halo centric orbit, which has a period of 7 days. And so you have to be able to get to that. Now, I performed the first rendezvous in space ever, and around the Earth, you go around about 89 minutes, you could call it close to an hour and a half. And, from that, we started out using a—transfer to demonstrate we had big—and it turns out we used a Russian technique. It was in a published version that came to me, and it was all in Russian, but—I didn't understand one word, but I understood the orbital diagrams, and it said rendezvous using the theory of Co-Elliptic Concentric Orbits, and that's basically what we did, only we simplified the end of it.

We'd have an inertial line of sight, in other words, with respect to the stars. That's inertially fixed. And so it's like flying an instrument landing system, for those of you that are pilots. You have—kind of bars, and so if the bar goes up, you pull back on the stick, and go up here, and you just thrust up. So it became very simple for a pilot to use. And at a certain angle you thrust toward it for the terminal phase. And so I did the first—one Gemini 9 I did three different types of rendezvous, and one of them I said don't ever do again unless it's an emergency. That's an overhead ballistic intercept coming down. And then I did the first rendezvous around the Moon. And so—and then also I did the first international—I've done, because of assignments, more rendezvouses than anybody in the world. And I think I understand it very well.

I have some serious questions about the rendezvousing out in deep space. I won't say it's impossible, but I haven't yet seen what it—the simulations of it, or how you would do it, because we use the breaking out from—and the darkness, and the sunlight, and the stars as a background, and a target, and all this. And out in deep space it would be a different—of course, you could have—now star trackers that can help you. But we could launch about anytime off the Moon and get back, at least once every 2 hours, because orbital period is 2 hours around the Moon. And here 7 days—you can't launch every hour. And it's—the only way you're going to change things is using—instead of orbital mechanics, you're going to be using a lot of propulsion. So I don't know the answer to it. So—I'm just saying I've got questions.

I want to say—let me add one other thing. They use the word "commercial." In Apollo, everything we flew on, everything we did, was commercial. It was all done by commercial companies. NASA did not build a thing. And maybe a few little hand tools were used on the Moon, and that was it. And—so everything was commercial, but yet NASA, as Mr. Young pointed out, had to lead, and had to show the way to go. And this—and what really worked out was—on the Saturn V, how good it did, and the Von Braun did an unbelievable job. Also the way NASA's team recovered after the tragic fire. But NASA had to lead, and it was commercial.

Chairwoman HORN. Thank you very much. Truly it is an honor to hear from both of you. Your experience, your expertise, and your insights are critical, and I think anybody that wasn't here today absolutely missed out, and I hope they watch the hearing later.

And before we bring the hearing to a close, I want to again, I think on behalf of all of us, express our gratitude for both of you, so thank you. And I should remind everyone the record will remain open for 2 weeks for additional statements from the Members, or any additional questions that the Committee may ask of witnesses, if you would do us that favor. And the witnesses are now excused, and the hearing is adjourned. Thank you.

[Whereupon, at 3:37 p.m., the Subcommittee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Lieutenant General Thomas P. Stafford

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

Keeping Our Sights on Mars Part 2: Structuring a Moon-Mars Program for Success

Questions for the Record to:

Lt. General Thomas P. Stafford, USAF (Ret.)

Submitted by Chairwoman Horn

1. This Subcommittee and the Full Committee have asked NASA for a plan along with a 5-year budget profile for NASA's Moon initiative. The Administration has said it will provide this information as part of NASA's Fiscal Year 2021 budget proposal, which is expected to be released in February 2020. What should the Committee be looking for in the plan?

2. A human landing system is a critical element of a future Moon-Mars architecture. How important is it for NASA to have insight and oversight into the development of a human landing system? What is the most effective means for ensuring that NASA has that insight and oversight?

3. You testified on the importance of leadership in implementing a Moon-Mars program. What are examples of essential leadership capabilities that NASA needs to effectively carry out a Moon-Mars program? What, if any, actions should Congress take to ensure NASA has the leadership required to implement a Moon-Mars program?

4. The 1991 Synthesis Group report you chaired, *America at the Threshold*, recommended greater interagency coordination, particularly among the Defense Department, Department of Energy and even the Department of the Interior. Would this recommendation apply to a Moon-Mars program undertaken today? How, in your view, might the other government agencies be involved in and contribute to a Moon-Mars program?

5. Past reports, such as the 2005 *Exploration Systems Architecture Study*, have suggested that revisions to acquisition authorities would be needed for a Moon-Mars program, while other reports, such as the 2009 *Augustine Commission Report*, indicated that NASA already has the necessary authorities to implement an effective acquisition strategy. What is your assessment? Are there additional acquisition authorities or new procurement approaches needed to accomplish a Moon-Mars program?

6. Changing political, economic, and budgetary climates have contributed to some of the failed attempts over past decades to restart the human exploration of deep space. To what extent should NASA or Congress try to build safeguards into a human exploration program to minimize the setbacks from such changes? As the Subcommittee works to reauthorize NASA, what priorities do you have for a NASA Authorization, especially with respect to the human exploration program?

7. Many reports of blue-ribbon panels that have offered advice on the nation's human exploration program have noted the importance of a workforce with a strong systems engineering capability. What actions can NASA and its contractors take to ensure NASA has a robust systems engineering workforce?

Following are the answers to the seven questions that were submitted to Lt. Stafford by Chairwoman Horn concerning NASA keeping their sites on structuring a Moon-Mars program for success.

1. The Sub Committee should look to see if the NASA plan with its five-year budget profile for the NASA Moon initiative has a realistic architecture that has a high probability of success. This has to be accomplished with a budget profile to support a plan which includes adequate resources. Based upon my experience of human space flight and the many committees I have served; the present architecture has a low probability of success. It is unrealistic to have seven launches with 17 critical operational nodes to provide or have one lunar landing. The plan should show enhancement of approximately 25 additional experienced individuals to be located at NASA Headquarters and a small additional number at each Center involved. Mr. Tom Young, in his testimony, also emphasized this aspect.

2. NASA should have strong insight and oversight of the program from the first day. One of the main factors of the success of the Gemini and Apollo programs was the fact that the astronauts, engineers and management were deeply involved and working side-by-side with the contractors from the start. Gemini flew ten missions in twenty months. Apollo went even faster and in just nine months flew five missions of which four were on giant Saturn V and three few to the Moon. Three of the Saturn V missions had two spacecraft the CSM and the LM, one in earth orbit and two to the moon. I commanded the first two spacecraft to the moon as Commander of Apollo X, and two months later Apollo XI landed. Various astronauts and engineers nearly lived in the manufacturing facilities of both programs. The present push "Commercial" would have been a disaster. The commercial public companies built all of the spacecraft and boosters, but NASA wrote all of the requirements, and had personnel working side-by-side with their contractor counterparts.

3. The importance of leadership is a top priority. Both Mr. Tom Young and I discussed this issue. NASA Headquarters needs a minimum of an additional 25 experienced personnel, and each involved Center an addition of a lesser number of experienced personnel in leadership positions. Without this key element, you cannot expect a successful outcome of the Moon/Mars initiative. The Congress should provide language outlining this requirement.

4. The Synthesis Group Report, *America at the Threshold,* outlines the recommendation that NASA should work with other executive agencies (i.e. DOD, DOE, etc.). DOD is needed for a series of support items. The DOE has a critical role in helping to analyze the space radiation environment. They are critical in developing planetary nuclear electric power. For the Mars mission, they should provide nuclear reactor, Nuclear Thermal Reactor (NTR) in the manner as they did on NERVA the nuclear thermal rocket. The national academies may be tasked with specific issues.

5. Today, NASA should have enough flexibility to implement a rapid acquisition authority. The *2005 Exploration System Architecture Study* outlined this need primarily due to the

fact of excessive requirements and reviews that have evolved since we performed the Apollo program in such a rapid and successful fashion.

6. To ensure an effective program of human exploration of deep space, The Congress should write language for multi-year contracts. This will help minimize setbacks in changes in administrations and personnel. For more emphasis and information, please refer to my answer to question #7.

7. The great strong system capabilities that NASA had developed during Apollo had begun to deteriorate by the time the Space Shuttle had started to fly. The continual decrease in both NASA budget and personnel had started to be reversed and increased under President George H.W. Bush when he started the Space Explorations Initiative in July 1989, but then rapidly declined when the Clinton Administration took Office and cancelled all Human Deep Space Exploration. During the second term of President George W. Bush, under Dr. Michael Griffin (NASA Administrator). Mr. Doug Cook (NASA Associate Administrator for Deep Space), and Mr. Jeff Hanley, The Constellation Program Manager; a concerted effort was made to rebuild NASA's capability. However, with the Obama Administration, the change in philosophy, decrease in NASA's budget and NASA political appointees; the systems' engineering began to rapidly dissipate. Now, with the goal under President Donald Trump, one very important factor that keeps this going is the National Space Council. It was effective under President Kennedy, President Johnson, and President Nixon until he deactivated it. It was reactivated under President George H.W. Bush; deactivated under President Clinton. Now, it has been reactivated under President Donald Trump. Having observed the performance of NASA and The National Space Council over the last 50+ years, it is my recommendations The Congress pass legislation to authorize that the National Space Council is made a permanent acting entity.

Further, my observations of the use of the near rectilinear (NRO) halo centric orbit with a period of 6 ½ days and the gateway spacecraft presents a real issue to me. I agree with Mr. Tom Young when he said that Gateway is not needed for the Moon but that it might be useful for Mars but that it is yet to be determined. For spacecraft to arrive and depart from NRO to my knowledge in reviewing document no serious rendezvous simulations have been performed. Mr. Gerstenmaier stated several months ago that we have always flown rendezvous around the earth and the moon in a known gravity field and a new technique would be required using the NRO. Low Lunar Orbit (LLO) has a period of 120 minutes while NRO takes 6 ½ days and is highly elliptical. The orbital period in LLO provides launch opportunities every two hours and you have a fairly large launch window whereas NRO is highly elliptical and if there is an emergency or abort situation would be very difficult. In review, NRO, it appears that the people proposing this placed a target and may have forgotten Kepler's 2nd Law of Motion. I was a member of a group that determined that the most feasible way to develop standard rendezvous techniques was by utilizing some of the technical sources provided by the Soviets/Russians. It is known as the co-elliptic concentric orbit rendezvous. I also flew the first ever rendezvous in Gemini VI and demonstrated feasibility of rendezvous. As Commander of Gemini IX, I used this technique to perform three types of rendezvous. As Commander of Apollo X, I performed the first rendezvous around the moon. Later I performed the first International rendezvous and docking as Apollo Commander of

the Apollo-Soyuz Mission. In summary, I have flown more rendezvous than any other astronaut or cosmonaut.

My opinion regarding the NRO, this could lead to a disaster in many aspects if a rendezvous were required in an emergency abort situation. Apollo XVI flew in April 1972 and Apollo XVII flew in December 1972. Early in August 1972, between the two Apollo Missions, one of the largest recorded solar flares and storms suddenly occurred. The intensity of the solar flux reached the earth in the fastest time recorded. The magnetic pulse associated with the flares was so intense that it exploded nearly 4,000 US Navy underwater mines off the coast of Viet Nam during the conflict. Satellites and major power lines were all affected. The following is quoted from Wikipedia "...those inside an Apollo Command Module would be sheltered from 90% of incoming radiation, which would have exposed the astronauts to radiation sickness. A moon walker or one during an EVA in Earth orbit would have faced severe illness and potentially a fatal dose." Had the intense solar activity of early August occurred during a Mission, it would have forced contingency measures up to and including return to Earth for emergency medical treatment.

Responses by Mr. A. Thomas Young

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

Keeping Our Sights on Mars Part 2: Structuring a Moon-Mars Program for Success

Questions for the Record to:

Mr. A. Thomas Young

Submitted by Chairwoman Horn

1. This Subcommittee and the Full Committee have asked NASA for a plan along with a 5-year budget profile for NASA's Moon initiative. The Administration has said it will provide this information as part of NASA's Fiscal Year 2021 budget proposal, which is expected to be released in February 2020. What should the Committee be looking for in the plan?

2. A human landing system is a critical element of a future Moon-Mars architecture. How important is it for NASA to have insight and oversight into the development of a human landing system? What is the most effective means for ensuring that NASA has that insight and oversight?

3. You recently chaired the Independent Review Board (IRB) for the James Webb Space Telescope, or JWST, a large, complex development project for the agency. Are there lessons learned from managing and implementing that project that can apply to the human exploration program? Are there challenges or red flags you saw in conducting the JWST IRB that could also arise in implementing a Moon-Mars program?

4. You testified on the importance of leadership in implementing a Moon-Mars program. What are examples of essential leadership capabilities that NASA needs to effectively carry out a Moon-Mars program? What, if any, actions should Congress take to ensure NASA has the leadership required to implement a Moon-Mars program?

5. Your written testimony referred to relying on "*leadership from other government organizations, industry and academia*" in a Moon-Mars program? How would you recommend other agencies, industry, and academia be involved?

6. Past reports, such as the 2005 *Exploration Systems Architecture Study*, have suggested that revisions to acquisition authorities would be needed for a Moon-Mars program, while other reports, such as the 2009 *Augustine Commission Report*, indicated that NASA

already has the necessary authorities to implement an effective acquisition strategy. What is your assessment? Are there additional acquisition authorities or new procurement approaches needed to accomplish a Moon-Mars program?

7. We are experiencing an unacceptable gap in our ability to send humans into space. Can you comment on what lessons can be learned from this gap and what, if anything, Congress should do differently as we work to ensure a sustainable human exploration program going forward?

8. Changing political, economic, and budgetary climates have contributed to some of the failed attempts over past decades to restart the human exploration of deep space. To what extent should NASA or Congress try to build safeguards into a human exploration program to minimize the setbacks from such changes? As the Subcommittee works to reauthorize NASA, what priorities do you have for a NASA Authorization, especially with respect to the human exploration program?

9. Your written testimony recommends "*the budget must fund the most probable cost of the program.*" You go on to state that your "*understanding of NASA policy is that the most probable cost is defined as a 70/30 cost estimate.*" Can you expand on this comment and describe how NASA should approach budgeting and costs associated with a Moon-Mars program? Why does NASA's cost estimating process appear to be so difficult? What needs to change to improve the process and how can Congress ensure that the budgeting and costs associated with a Moon-Mars program are "the most probable cost of the program"?

10. Your written testimony also stresses the importance of a credible budget. When should NASA be able to produce such a budget for this multi-decadal undertaking? Or will they have to provide budgets for each phase? What level of detail can be reasonably included in a budget such that Congress has the necessary information to carry out oversight and monitor the program's progress?

A. Thomas Young

Response To Questions Submitted By Chairwoman Horn

1. I believe the Plan must be quite specific recognizing that it will be a living document evolving and changing as dictated by new information. It must include a clear and unambiguous goal and objectives, the technical and mission approach to accomplish the goal, a definition of technical challenges ,an implementation time line, the management and organization plan, the approach to contracting with industry for implementation, etc.

2. It is critically important that NASA has insight and oversight into the development of the human landing system including leadership of the endeavor. The most effective means of assuring NASA has this responsibility is the contracting approach with industry. NASA should be the owner of the landing system, not simply a buyer of seats and services.

3. The most important criteria for a large, complex space project is mission success. Mission Success is more important than schedule and cost. This does not mean that schedule and cost are not important. Responsibility for mission success cannot be delegated to the contractor. NASA and the contractor have a joint responsibility for mission success leadership. I recommend including the JWST IRB

Report as part of the RFP to industry with a requirement that the proposal include their approach to responding to each recommendation. The contractor's response should be included as part of the proposal evaluation.

4. I believe NASA requires at least an additional half dozen very senior, space project experienced leaders to accomplish the Moon-Mars Project. As was the case in filling the Human Space Flight AA position, these positions will need to be filled by candidates external to NASA. Congress can help highlight the need and provide hiring authority that will facilitate responding to this critical need. I also believe the Moon-Mars Project will require systems engineering support similar to that proved to Apollo by Bellcomm.

5. I believe the senior, experienced personnel cited in the answer to Question 4 must come from other parts of the Government, industry and academia. The Space Council can be most helpful in this endeavor by supporting the need and assisting in recruiting appropriate candidates.

6. I do not believe additional acquisition authorities or new procurement approaches are required. The authority currently exist to provide a RFP to industry defining NASA requirements, to select the best contractor or contractors to meet NASA's requirements, to establish a cost type contract with appropriate performance incentives, etc. This should not be made more complex than required. The Moon-

Mars Project will be challenging enough without adding management and contracting experiments and complexity.

7. I believe the gap is self inflicted. It is the result of one or more of the following causes. Causes include a lack of leadership, a lack of an approved plan, a lack of OMB and/or Congressional support or a lack of continuity as Administrations changes. Each of these causes must be corrected.

8. The context of Question 8 is certainly true. I offer my written testimony as an initial response

9. There have been several studies, some of which I have had the privilege of chairing, that conclude that failure to budget to the most probable cost is the largest reason for cost increases. I might note that requirements creep is second. There is significant evidence that a statistical 80/20 represents the most probable cost. NASA has stated that a portfolio of projects all at 70/30 results in 80/20 for the total portfolio. This is probably true if all the projects are similar. If a project is different as is the case for Moon-Mars and other projects such as JWST and SLS, each must be treated individually. I believe Moon-Mars should be budgeted at 80/20.

While challenging, I do not believe cost estimating for space projects is extremely difficult, It is certainly true that the better a project is defined, the better the cost estimate. The difficulty occurs when there

is more attention given to budgeting to the lowest credible cost as opposed to the most probable cost Budgeting to the lowest credible cost probably assures a project will overrun approximately 100%.

The required action is that NASA leadership, OMB and Congress require that projects such as Moon-Mars be budgeted at the 80/20 cost estimate.

10. I do not believe it is appropriate to budget the Moon-Mars Project for the total time period from now to humans on Mars. Current lack of knowledge would result in the budged not being credible. I suggest that the initial budget be for approximately 5 years with a significant milestone, such as the initial human landing on the moon, at the end of the period. The "5 year budget" should be a complete budget at the 80/20 cost estimate.

Appendix II

Additional Material for the Record

LETTER SUBMITTED BY REPRESENTATIVES KENDRA HORN AND BRIAN BABIN

11/9/2019

Representative Kendra Horn
415 Cannon HOB
Washington, DC 20515

Representative Brian Babin
2236 Rayburn House Office Building
Washington, DC 20515

Dear Chairwoman Horn and Ranking Member Babin:

The Planetary Society—the world's largest independent, nonprofit space organization, which represents more than 50,000 individuals—commends your subcommittee for its hearing, "Keeping Our Sights on Mars Part 2: Structuring a Moon-Mars Program for Success." For nearly four decades, The Planetary Society has supported human and robotic exploration of the planets, with Mars serving as the ultimate destination for human spaceflight.

We should not minimize how challenging it will be for NASA and its international and commercial partners to land the first humans on Mars, and return them safely to Earth. Mars is a thousand times more distant than the Moon, which creates significant technical challenges for human safety, communications, engineering reliability, and risk management. Fortunately, none of these challenges is insurmountable, given proper resources and time. The primary hurdle standing between humanity and the Red Planet has been, and remains, political.

To this end, we are pleased to see the members of this committee remain vigilant as NASA trains its near-term focus on returning astronauts to the Moon. Thanks to its relative proximity, the Moon provides a destination for extended human presence beyond low-Earth orbit and for testing technologies that will enable longer-term human exploration.

However, human exploration of the Moon is easy, and it will not necessarily provide a "training ground" for Mars exploration. The Apollo program, for all of its successes, was ultimately a dead end in space exploration. We must not let that happen again. NASA and Congress must take preemptive steps to ensure that lunar exploration feeds directly into a long-term effort to send humans to Mars.

With a 2024 deadline, NASA faces immediate, engineering and organizational challenges that are specific to the Moon that are growing more pressing as the lunar lander effort matures. Addressing these challenges by developing solutions designed specifically for the Moon, and not transferrable to Mars exploration, presents tempting (and budget-friendly) shortcuts for program managers and NASA leadership facing political pressure to move quickly and act decisively. In other words, NASA is incentivized to solve for the Moon and not seek out general solutions for Mars exploration. Absent strong oversight and support from Congress, the United States could easily find itself in a lunar cul-de-sac of hardware and operational expertise, no closer to Mars than it was at the end of the Apollo program, nearly half a century ago. The 2014 report by the National Academies, *Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration*, identified dead-end elements within a theoretical Moon-to-Mars program, as well as potential transitional elements that could benefit such an effort. The National Academies report should serve as a template for both oversight and programmatic design of NASA's current effort.

Last year, The Planetary Society defined a set of principles for human spaceflight that, if pursued by NASA and by Congress, would enable a durable, visionary, and exciting humans-to-Mars effort. We urge the committee and your colleagues in Congress to consider the following items in the coming years.

The Planetary Society recommends that NASA:

Develop a humans-to-Mars plan with clear milestones, publicizing a timeline and budget that will permit external parties and Congress can measure NASA's progress.

Absent a timeline with clearly-defined milestones, Congress and other external organizations have no metric by which to evaluate progress (or lack thereof). Committing to a timeline ensures accountability and provides transparency to the taxpayer. NASA has made progress on this front for its Artemis program, but its plans for Mars remain vague and ill-defined. Consequently, evaluating NASA's progress on sending humans to Mars is currently impossible.

Prioritize human spaceflight technology development in areas that sustain human psychological and physical health for long-duration spaceflight.

Many key technologies necessary for the long-duration survival of humans in space have not yet been proven. In particular, technologies related to human physical and psychological health should be prioritized. A serious Moon-to-Mars program, with a timeline and realistic milestones, provides a framework by which NASA can prioritize essential technology development projects in the context of immediacy, complexity, applicability, and cost.

Engage the scientific community from the earliest stages of planning to ensure significant scientific return from its human spaceflight program.

Scientific investigation provides an enduring return on investment from space exploration, not just for its enrichment of human knowledge, but in the vast potential value of the discoveries themselves to improve our lives and our understanding of the Cosmos.

In order to ensure significant and valuable scientific return on the public's investment in human spaceflight, the scientific community should be incorporated into the planning and design teams of human spaceflight projects as early as possible. Incorporating scientific goals into the exploration effort would provide useful constraints on mission and hardware design, and would engage a worldwide coalition of scientists and researchers.

Plan for an orderly transition away from the International Space Station (ISS) by the mid-2020s, unless adequate budget increases are provided to support concurrent deep space exploration efforts.

The International Space Station is a triumph of engineering and international cooperation. It also represents a significant annual cost of approximately $4 billion to operate, supply, and crew. NASA and its partners do not currently have the budget to sustain both the ISS and develop a robust human deep-space exploration program, though the supplementary request in the President's FY 2020 budget was a promising step. If new funding is not forthcoming, the nation's priority must be on the deep-space exploration effort, and NASA therefore must transition away from its primary funding and management responsibility of the ISS. If the nation

is not willing to provide additional funding, we should not shoulder NASA with an unfunded mandate to explore the Moon and Mars.

We wish to again acknowledge the value of this hearing and importance of the committee's continued oversight of NASA's long-term human exploration plans.

Sincerely,

Casey Dreier
Senior Space Policy Adviser
The Planetary Society

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