CHARTING A COURSE: EXPERT PERSPECTIVES ON NASA'S HUMAN EXPLORATION PROPOSALS

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED FOURTEENTH CONGRESS

FIRST SESSION

February 3, 2016

Serial No. 114–58

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

20–828PDF WASHINGTON : 2017

For sale by the Superintendent of Documents, U.S. Government Publishing Office
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CHARTING A COURSE: EXPERT PERSPECTIVES ON NASA'S HUMAN EXPLORATION PROPOSALS

WEDNESDAY, FEBRUARY 3, 2016

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

The Subcommittee met, pursuant to call, at 10:04 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Brian Babin [Chairman of the Subcommittee] presiding.

LAMAR S. SMITH, Texas
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Subcommittee on Space

Charting a Course: Expert Perspectives on NASA's Human Exploration Proposals

Wednesday, February 3, 2016
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

Witnesses

Mr. Tom Young, Former Director, Goddard Space Flight Center, NASA; Former President and Chief Operating Officer, Martin Marietta Corporation

Dr. John C. Sommerer, Chair, Technical Panel, Pathways to Exploration Report, National Academy of Sciences

Dr. Paul Spudis, Senior Scientist, Lunar and Planetary Institute

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

Charting a Course: Expert Perspectives on NASA's Human Exploration Proposals

Wednesday, February 3, 2016
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

Purpose

On Wednesday, February 3, 2016, the Space Subcommittee will hold a hearing titled *Charting a Course: Expert Perspectives on NASA's Human Exploration Proposals.* The purpose of this hearing is to examine the options for intermediate missions as well as research, technology, and systems needed before NASA can safely and effectively carry out a human mission to Mars, while maintaining a constancy of purpose and steady technical progress through the next Presidential Administration and beyond.

Witnesses

- **Mr. Tom Young**, Former Director, Goddard Space Flight Center, NASA; Former President and Chief Operating Officer, Martin Marietta Corporation
- **Dr. John C. Sommerer**, Chair, Technical Panel, Pathways to Exploration Report, National Academy of Sciences
- **Dr. Paul Spudis**, Senior Scientist, Lunar and Planetary Institute

Background

Following the Space Shuttle *Columbia* accident in February 2003 and the subsequent investigation into its cause, President George W. Bush announced a new "Vision for Space Exploration" on January 14, 2004, to reinvigorate and redirect NASA's human exploration program beyond the International Space Station. The plan focused on the next steps for low-Earth orbit and beyond. It also provided a general vision that the NASA Administrator could use to "implement an integrated, long-term robotic and human exploration program structured with measurable milestones and executed on the basis of available resources, accumulated experience, and technology readiness."[1] The plan included four main goals and objectives: to implement a sustained and affordable human and robotic program to explore the solar system; to extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations; to develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and promote international and commercial participation in exploration to further U.S. scientific, security, and

[1] National Aeronautics and Space Administration-*The Vision for Space Exploration, February 2004.* Retrieved at http://www.nasa.gov/pdf/55583main_vision_space_exploration2.pdf

economic interests.[2] The Constellation Program was born out of the Vision for Space Exploration of 2004 and the work for this new program began with NASA's budget request for fiscal year 2005.

After his appointment as Administrator in April 2005, Dr. Mike Griffin ordered a review of NASA's exploration architecture called the "Exploration Systems Architecture Study" (ESAS) to carry out this vision. After the completion of the study, NASA began, with the concurrence of Congress, to restructure the exploration program with an emphasis on acceleration of the development of capabilities to ferry astronauts to the International Space Station.[3] The study recommended the development of a Space Shuttle-derived launch architecture[4] and an exploration vehicle that was capable of carrying cargo and crew to the Space Station as well as crew to the Moon and Mars.[5] Congress codified the majority of the ESAS plan in the National Aeronautics and Space Administration Authorization Act of 2005 (P.L. 109-155), understanding the milestone schedule was based primarily on the ability to "go-as-we-can-afford-to-pay."[6]

In 2009, President Obama ordered a review of the Constellation program and acting NASA Administrator Chris Scolese established the "Review of U.S. Human Spaceflight Plans Committee" (the Commission and also known as the "Augustine Commission") chaired by Norman R. Augustine. The charter for the Commission called for an "independent review of ongoing U.S. human space flight plans and programs, as well as alternatives, to ensure the Nation is pursuing the best trajectory for the future of human space flight—one that is safe, innovative, affordable, and sustainable."[7] The Commission released its final report on October 22, 2009.[8]

The Commission found that "the ultimate goal of human exploration is to chart a path for human expansion into the solar system,"[9] but that "since Constellation's inception, the program has faced a mismatch between funding and program content"[10] and "[d]ifferences between the original Constellation program planning budget and the actual implementation budget, coupled with technical problems that have been encountered on the [programs], have produced the most significant overall impacts to the execution of the Constellation program."[11] The Commission offered five options for the future of the human exploration program, two of which complied with the FY2010 budget profile of the Obama Administration for the Constellation program.[12] However, the Commission noted that neither of these two options would "permit human exploration to continue in any meaningful way."[13]

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[2] *Ibid.*
[3] National Aeronautics and Space Administration Exploration Systems Architecture Study (pg 59). Retrieved at http://www.nasa.gov/pdf/140632main_ESAS_02.pdf
[4] *Ibid.* at pg 717
[5] *Ibid.* at pg 714
[6] Public Law 109-155 NASA Authorization Act of 2005: https://www.gpo.gov/fdsys/pkg/PLAW-109publ155/pdf/PLAW-109publ155.pdf
[7] Charter of the "Review of U.S. Human Spaceflight Plans Committee". retrieved at http://www.nasa.gov/pdf/354415main_Charter%20-%20Signed%20-%20Clean.pdf
[8] Final Report of the "Review of U.S. Human Spaceflight Plans Committee". Retrieved at: http://www.nasa.gov/pdf/396093main_HSF_Cmte_FinalReport.pdf
[9] *Ibid.* at pg 9
[10] *Ibid.* at pg 58
[11] *Ibid.* at pg 59
[12] http://www.nasa.gov/pdf/345955main_8_Exploration_%20FY_2010_UPDATED_final.pdf. Note the significant change in the budget projection for the Constellation program from the FY 2010 budget profile on page EXP-2.
[13] Final Report of the "Review of U.S. Human Spaceflight Plans Committee." P. 16. Retrieved at: http://www.nasa.gov/pdf/396093main_HSF_Cmte_FinalReport.pdf

In February 2010, President Obama offered a budget for fiscal year 2011 that proposed to cancel the Constellation program.[14] Later that same year, Congress authorized some of the changes to the human exploration program sought by the President[15] as outlined in a speech on April 15, 2010. In this speech at the Kennedy Space Center he revealed his strategy for the future of human exploration which canceled a return mission to the Moon, saying, "I understand that some believe that we should attempt a return to the surface of the Moon first, as previously planned. But I just have to say pretty bluntly here: We've been there before… Early in the next decade, a set of crewed flights will test and prove the systems required for exploration beyond low Earth orbit. And by 2025, we expect new spacecraft designed for long journeys to allow us to begin the first-ever crewed missions beyond the Moon into deep space. So we'll start -- we'll start by sending astronauts to an asteroid for the first time in history. By the mid-2030s, I believe we can send humans to orbit Mars and return them safely to Earth. And a landing on Mars will follow."[16]

Stepping Stones to Mars

The NASA Authorization Act of 2015 (H.R. 810), which passed the House of Representatives unanimously last February, included a requirement that NASA produce a "human exploration roadmap."[17] Among other things, the roadmap would include "specific capabilities and technologies necessary to extend human presence to the surface of Mars and the sets and sequences of missions required to demonstrate such capabilities and technologies."[18] As the Senate has not passed a NASA Authorization act since 2010, the Administration has received no guidance from Congress on its programs since 2013, when the NASA Authorization Act of 2010 expired.

As NASA prepares to take the next steps in human exploration of the solar system, there remain many unanswered questions about the correct path to Mars and beyond. The Apollo Program was not a straight shot to the Moon; it included several precursor missions to test new capabilities and gain experience on the way to the Moon, including Projects Mercury and Gemini. In much the same way, NASA will need to acquire new capabilities to travel to Mars and beyond. The two most commonly discussed possibilities for precursor missions to Mars involve crewed missions to the Moon or an asteroid.

In October 2015, NASA released a document titled *NASA's Journey to Mars, Pioneering Next Steps in Space Exploration*.[19] In the report, the agency provided general descriptions about the future of human exploration to Mars including the Asteroid Retrieval Mission (ARM) as a necessary "near term opportunity to demonstrate several capabilities important for longer-duration, deep-space missions…"[20] This report did not mention any potential missions for the lunar surface.

The importance of keeping human exploration program on track across Presidential transitions has been an ongoing challenge. Multiple NASA advisory panels and commissions that study the human

[14] President's Budget Request for the National Aeronautics and Space Administration, Fiscal Year 2011. Retrieved at http://www.nasa.gov/news/budget/2011.html
[15] Public Law 111-267: National Aeronautics and Space Administration Authorization Act of 2010: https://www.congress.gov/111/plaws/publ267/PLAW-111publ267.pdf
[16] Speech by President Obama at Kennedy Space Center on April 15, 2010 http://www.nasa.gov/news/media/trans/obama_ksc_trans.html
[17] H.R. 810, the National Aeronautics and Space Administration Authorization Act of 2015, Section 202: https://www.congress.gov/114/bills/hr810/BILLS-114hr810rfs.pdf
[18] *Ibid.*
[19] "NASA's Journey to Mars, Pioneering Next Steps in Space Exploration." Released in October of 2015. Retrieved at http://www.nasa.gov/sites/default/files/atoms/files/journey-to-mars-next-steps-20151008_508.pdf
[20] *Ibid.* at pg. 21.

exploration program have concluded that the importance of keeping the program of record on track is paramount to ensuring budget and schedule stability.

In preparation for the future of NASA's human exploration program beyond the current Administration, the NASA Advisory Council (NAC) recently released a public recommendation to the Administrator that NASA should further develop its plan for future human exploration. The NAC concluded that without further definition to these plans, it would impair the ability of the next Administration to propose a budget that "adequately support[s] NASA's Human Exploration Program."[21]

NASA Administrator Charles Bolden recently reiterated his concerns about maintaining the current track of exploration programs. In remarks at the Center for American Progress, the Administrator commented that, ""If we change our minds at any time in the next three or four years, which always is a risk when you go through a government transition, my belief is that we're doomed." He also remarked that constant restarts of the exploration programs have a negative effect on the overall effort, "I think we've been through enough 'start overs' to know that people grow weary. People like to see something where you're persistent."[22]

Additionally, the Aerospace Safety Advisory Panel (ASAP) reissued a call for constancy of purpose in its annual report released on January 13, 2016. The panel stated, "As in prior reports, the ASAP urges constancy of purpose. Failing to stay the course with current programs of record will make it an even longer, costlier, and potentially less safe trip to Mars."[23]

Lunar Mission

The *Vision for Space Exploration* called for a return to the Moon by 2020 as a stepping stone to other locations, and NASA has continued various lunar science projects such as the Lunar Reconnaissance Orbiter (LRO) and the Gravity Recovery and Interior Laboratory (GRAIL). The Constellation program was ideally suited for a human landing on the Moon, to include development of a lunar lander called *Altair* as one of the systems to develop. Since the cancellation of the Constellation program, there is no longer a lunar lander under development.

There are several compelling reasons for using the Moon as a training ground and test bed to prepare for more complex missions. Landing on the Moon would develop technical capabilities for landing on and launching from a large celestial body, something NASA has not done for more than four decades.[24] According to a report published by the Planetary Society, "getting humans to Mars by the 2030s will require new hardware and space-based operations that must be demonstrated closer to Earth."[25] The report goes on to explain the necessity of returning humans to the surface of

[21] NASA Advisory Council Recommendation to the Administrator 2015 04-04-01 (Council-01). December 3, 2015. http://www.nasa.gov/sites/default/files/atoms/files/final_recommendations_dec2015_tagged.pdf
[22] "Bolden: NASA "Doomed" if Next President Dumps Journey to Mars" October 29, 2015. http://spacenews.com/bolden-nasa-doomed-if-next-president-dumps-journey-to-mars/#sthash.v4VwiLUN.dpuf
[23] Aerospace Safety Advisory Panel Annual Report for 2015. Retrieved at http://oiir.hq.nasa.gov/asap/documents/2015_ASAP_Annual_Report.pdf
[24] The last time humans landed on the moon was Apollo 17 on December 7, 1972.
[25] Humans Orbiting Mars: A Critical Step Toward the Red Planet. September 28, 2015. http://planetary.s3.amazonaws.com/assets/pdfs/advocacy/2015.Planetary-Society--Humans-Orbiting-Mars-Workshop-Report-%e5BFinal.v2%5D.pdf

the Moon "within the context of an end-to-end test of the Mars lander system and a simulation of Mars surface operations."[26]

Establishing a semi-permanent or permanent presence on the Moon such as the lunar outpost referenced in the NASA Authorization Acts of 2005 and 2008,[27] would give astronauts an opportunity to work and live in an environment radically different from Earth, in much the same way explorers on Mars would need to work and live. Ultimately, operating on another planet will require training and preparation, the Moon seems like a logical place to do this training.

On the international front, there appears to be continued enthusiasm for a mission to the Moon."[28] Recently, Jan Woerner, the Director General of the European Space Agency, proposed the development of an international Moon "village" as a next step for international human exploration efforts.[29] Additionally, Roscosmos Energia announced plans for a human mission to the lunar surface in 2029.[30]

Although there is increased energy from international partners, NASA continues to rebuff any notion of landing humans on the surface of the moon. Both President Obama and Administrator Bolden have said that landing humans on the surface of the moon is not a priority.[31]

Asteroid Mission

The National Space Policy issued by President Obama in April 2010, and released formally later that year, envisioned sending humans to an asteroid by the year 2025 beyond lunar orbit into "deep space."[32] The National Research Council issued a report in December 2014 which stated that "[t]he committee has seen little evidence that a current stated goal for NASA's human spaceflight program—namely, to visit an asteroid by 2025—has been widely accepted as a compelling destination by NASA's own workforce, by the nation as a whole, or by the international community."[33]

The Administration proposed a revised asteroid mission with the FY2014 budget request. The mission concept proposed by the Administration features a robotic capture and redirection of a small near Earth asteroid (NEA) to a deep retrograde lunar orbit for astronauts to visit rather than sending Astronauts to an asteroid in deep space.

After significant study efforts and criticism from scientists, engineers, and policy-makers, the Administration proposed another revision to the mission in March 2015. This time, the proposal included a robotic sample capture and retrieval mission. Under the revised proposal, a robotic spacecraft would go to a large asteroid, pull a boulder off an asteroid, and return it to a distant

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[26] *Ibid.*
[27] 51 USC 70505
[28] NASA's Strategic Direction and the Need for a National Consensus http://www.nap.edu/catalog.php?record_id=18248
[29] "Moon village is best way to replace International Space Station - ESA head" Reuters News Service, January 15, 2016. http://www.reuters.com/article/europe-space-moon-idUSL8N14Z1WB
[30] "Russia's Big Plan To Finally Put Cosmonauts on the Moon" January 6, 2016. http://www.popularmechanics.com/space/moon-mars/a18849/russia-plan-cosmonauts-moon/
[31] "As NASA Shrugs, FAA Looks at Leadership Role in Global Moon Village," November 3, 2015. http://spacenews.com/as-nasa-shrugs-faa-looks-at-leadership-role-in-global-moon-village/
[32] National Space Policy. Released on June 28, 2010. Pg. 11. Retrieved at https://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf
[33] National Research Council Report: Pathways to Exploration. Retrieved at http://www.nap.edu/catalog/18801/pathways-to-exploration-rationales-and-approaches-for-a-us-program

retrograde lunar orbit for exploration by astronauts.[34] As with previous proposals, there is no budget estimate for the mission.

At its meeting in April 2015, the NASA Advisory Council issued a recommendation to the Administrator that NASA's stated use of solar electric propulsion in the ARM mission would "likely be an important part of an architecture to send humans to Mars." And that "maneuvering a large test mass is not necessary to provide a valid in-space test of a new SEP Stage." The NAC concluded its recommendation to the Administrator by saying, "instead of relocating a boulder from an asteroid, [the NAC] suggests that a more important and exciting first use of this new SEP stage would be a round trip mission to Mars."[35]

NASA recently published for comment a draft report on the architecture of the mission referred to as the FAST (Formulation Assessment and Support Team) report. The purpose of the report was to "to provide timely inputs for mission requirement formulation in support of the Asteroid Redirect Robotic Mission (ARRM) Requirements Closure Technical Interchange Meeting (TIM) in mid-December of 2015, to assist in developing an initial list of potential mission investigations, and to provide input on potential hosted payloads and partnerships."[36]

The FAST report provided background on the purpose of ARRM, responded to common questions about the mission, provided analysis of potential science investigations, and evaluated the necessity of the mission for future human exploration efforts. The report was released on the Monday before the Thanksgiving Day holiday and public comments were required within 10 days before the comment period closed.

Issues

As Congress begins planning for the first budget year under a different President, there are several issues under consideration and outstanding questions, among them:

- How can Congress provide a better constancy of purpose for NASA's human exploration program so that it does not endure another costly cancelation as the Constellation Program and other, previous NASA programs?
- What are the most important skills, technologies, and processes necessary for future Mars missions and how should the development of these elements be phased?
- What advantages and disadvantages are there of missions to the Moon or asteroids or other destinations?
- How do NASA's plans for future human exploration missions affect the United States' relationships with international partners?
- How should NASA incorporate international participation as well as commercial and philanthropically-funded programs in its human spaceflight plans and programs beyond low Earth orbit?

Appendix- Reports on Space Exploration

[34] NASA Announces Next Steps on Journey to Mars: Progress on Asteroid Initiative. NASA Press Release, March 25, 2015. http://www.nasa.gov/press/2015/march/nasa-announces-next-steps-on-journey-to-mars-progress-on-asteroid-initiative

[35] NASA Advisory Council Recommendations to the Administrator, April 9-10, 2015. Retrieved at http://www.nasa.gov/sites/default/files/atoms/files/april9-10_finalrecom-tagged.pdf

[36] Draft Formulation Assessment and Support Team Report. Published November 23, 2015. https://www.nasa.gov/sites/default/files/atoms/files/fast-final-report-draft-for-public-comment.pdf

1986 - The National Commission on Space (Paine Commission Report)
http://www.nasa.gov/pdf/383341main_60%20-%2020090814.5.The%20Report%20of%20the%20National%20Commission%20on%20Space.pdf

1987 - NASA Leadership and America's Future in Space: A Report to the Administrator (Ride Report)
http://history.nasa.gov/riderep/main.PDF

1990 – Advisory Committee on the Future of the U.S. Space Program (Augustine Commission Report)
http://www.hq.nasa.gov/office/pao/History/augustine/racfup1.htm

1991 – The Synthesis Group (The Stafford Report)
http://history.nasa.gov/staffordrep/main_toc.PDF

1991 - Office of Technology Assessment: Exploring the Moon and Mars
http://history.nasa.gov/32992.pdf

1993 – The National Space Council Report on the U.S. Space Program
http://history.nasa.gov/33082.pt1.pdf

2004 – President's Commission on Implementation of United States Space Exploration Policy (Aldridge Commission Report)
http://history.nasa.gov/aldridge_commission_report_june2004.pdf

2009 – Review of U.S. Human Space Flight Plans Committee (Augustine Commission Report)
http://www.nasa.gov/pdf/396093main_HSF_Cmte_FinalReport.pdf

Chairman BABIN. Okay. The Subcommittee on Space will come to order.

Without objection, the Chair is authorized to declare recesses of the Subcommittee at any time.

Welcome to today's hearing titled "Charting a Course: Expert Perspectives on NASA's Human Exploration Proposals," and I would like to recognize myself for five minutes for an opening statement.

Placing a man on the Moon and returning him safely is widely considered one of humanity's greatest achievements. It cemented America's leadership on the world stage and demonstrated our technological superiority during the Cold War. Since then, NASA has made steady progress towards learning to live and work in space with the space shuttle and space station.

Today we find ourselves at an intersection. Do we, as a nation, retreat from the cosmos, or do we take that next first step into the unknown? There appears to be a consensus that the horizon goal of America's human exploration program is to land on the surface of Mars. But how will we get there? What are the intermediate stepping stones on that pathway to Mars? How do we avoid costly and avoidable detours? How do we ensure a sustainable program rather than a one-off stunt? And how do we ensure the next Administration does not wipe the slate clean, erasing all the hard work of the last five years? These are all questions that we must address in this and future hearings.

The SLS and Orion systems are critical to the success of our deep space human exploration program. Their development and testing is of the utmost importance to the Committee, to Congress, and to the nation. We have come too far now to see a costly and destructive cancellation. However, the use of these assets and the missions and mission sets on the journey to Mars need to be better defined. As the NASA Advisory Council recently stated in a recommendation to the Administrator, the absence of a more fully developed plan would impair the ability of the next Administration to propose a budget that adequately supports NASA's human exploration program.

And while the administration has not provided many details on the plan for the journey to Mars, it has proposed possible mission options. For example, the Administration has proposed an asteroid mission as the next step for human exploration. This has been caveated and altered multiple times, but generally speaking, the Administration believes human astronauts should interact with an asteroid in cislunar space sometime in the next decade as a next step on its journey to Mars.

Despite opposition from space policy experts, scientists, and engineers, the Administration as recently as last week announced early design work for the asteroid mission's spacecraft bus. With only nine meaningful months remaining in this Administration, it is puzzling that they continue to press ahead with the mission despite widespread criticism and doubt over its efficacy.

The National Academy of Sciences released a study on human exploration called the "Pathways to Exploration." In this report the Committee on Human Spaceflight determined that the ARM mission largely contributed to dead-end technologies that could not

reasonably feed forward into a human mission to Mars. Last year, the NASA Advisory Committee suggested to the Administration that a more valuable use of NASA's time and money would be a solar electric propulsion demonstration mission to Mars and back as opposed to the asteroid mission.

Alternatives to the asteroid mission proposed by the President have become ubiquitous in the policy discussions. For example, Jan Woerner, the European Space Agency Director General, has spent the last year advocating for an international lunar base. The recent Humans Orbiting Mars workshop presented a compelling, realistic, and affordable path to Mars. Also, several members of this Committee have suggestions and legislation as well to that effect. As the Administration ignores these proposals despite a groundswell of support from scientists and engineers, we must look beyond what is politically expedient today and get ready for the next few decades in spaceflight.

As we prepare for the next Presidents' Administration, we must ensure that the plan in place for human exploration is based on sound engineering, planning, design, and management principles.

We have asked our witnesses today to give us their expert opinions in the way forward. This hearing is an opportunity to build consensus on the way forward for human spaceflight. Human exploration has a long and storied history of being nonpartisan. It is not a Republican, it is not Democrat; it is an American issue. We need to get the politics out of these important programs for our nation's sake.

There are thousands of men and women in this country whose days are impacted by the decisions that we make in this very building. It is easy for people confined to the beltway bubble to forget that our pride as Americans comes from the hard work and determination to make this world better. The men and women at NASA working on our human exploration program are not pawns to be moved around a chess board in the latest game of chicken that the Administration chooses to play with Congress. We must ensure NASA's work focuses on the will of the people, not the political whims of whatever President is in office at that particular time.

NASA's human exploration program has been through a tumultuous seven years, and with a new President to be chosen by the end of this year, we must ensure that there is a constancy of purpose in our planning and a surefooted roadmap in place for the future.

[The prepared statement of Chairman Babin follows:]

COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Lamar Smith, Chairman

For Immediate Release
February 3, 2016

Media Contact: Laura Crist
(202) 225-6371

Statement of Space Subcommittee Chairman Brian Babin (R-Texas)
Charting a Course: Expert Perspectives on NASA's Human Exploration Proposals

Chairman Babin: Placing a man on the Moon and returning him safely is widely considered one of humanity's greatest achievements. It cemented America's leadership on the world stage and demonstrated our technological superiority during the Cold War. Since then, NASA has made steady progress towards learning to live and work in space with the space shuttle and space station.

Today we find ourselves at an intersection. Do we, as a nation, retreat from the cosmos, or do we take that next first step into the unknown? There appears to be consensus that the horizon goal of America's human exploration program is to land on the surface of Mars. But how will we get there? What are the intermediate stepping stones on that pathway to Mars? How do we avoid costly and avoidable detours? How do we ensure a sustainable program rather than a "one-off" stunt? And how do we ensure the next administration does not wipe the slate clean, erasing all the hard work of the last five years. These are all questions that we must address in this and future hearings.

The SLS and Orion systems are critical to the success of our deep space human exploration program. Their development and testing is of the utmost importance to the Committee, Congress, and the nation. We have come too far now to see a costly and destructive cancellation. However, the use of these assets and the missions and mission-sets on the "Journey to Mars" need to be better defined. As the NASA Advisory Council recently stated in a recommendation to the Administrator, the absence of a more fully developed plan would impair the ability of the next administration to propose a budget that "adequately support[s] NASA's Human Exploration Program."

While the administration has not provided many details on the plan for the "Journey to Mars," it has proposed possible mission options. For example, the administration has proposed an asteroid mission as the next step for human exploration. This has been caveated and altered multiple times, but generally speaking, the administration believes human astronauts should interact with an asteroid in cis-lunar space sometime in the next decade as a next step on its "Journey to Mars."

Despite opposition from space policy experts, scientists, and engineers, the administration as recently as last week announced early design work for the Asteroid Mission's spacecraft bus. With only nine meaningful months remaining in this administration, it is puzzling that they continue to press ahead with the mission despite widespread criticism and doubt over its efficacy.

The National Academy of Sciences released a study on human exploration called the "Pathways to Exploration." In this report the Committee on Human Spaceflight determined that the ARM mission largely contributed to "dead-end" technologies that could not reasonably feed forward into a human mission to Mars. Last year, the NASA Advisory Committee suggested to the Administrator that a more valuable use of NASA's time and money would be a Solar Electric Propulsion demonstration mission to Mars and back as opposed to the Asteroid mission.

Alternatives to the Asteroid mission proposed by the President have become ubiquitous in the policy discussions. For example, Jan Woerner, the European Space Agency Director General, has spent the last year advocating for an international lunar base. The recent "Humans Orbiting Mars" workshop presented a compelling, realistic, and affordable path to Mars. Also, several members of this Committee have suggestions and legislation as well. As the administration ignores these proposals despite a groundswell of support from scientists and engineers, we must look beyond what is politically expedient today and get ready for the next few decades in spaceflight.

As we prepare for the next President's administration, we must ensure that the plan in place for human exploration is based on sound engineering, planning, design, and management principles.

We have asked our witnesses today to give us their expert opinions for the way forward. This hearing is an opportunity to build consensus on the way forward for human spaceflight. Human exploration has a long and storied history of being non-partisan. It is not a Republican or Democrat issue, it is an American issue. We need to get the politics out of these important programs.

There are thousands of men and women in this country whose days are impacted by the decisions we make in this building. It is easy for people confined to the beltway bubble to forget that our pride as Americans comes from the hard work and determination to make this world better. The men and women at NASA working on our human exploration program are not pawns to be moved around a chess board in the latest game of chicken that the administration chooses to play with Congress. We must ensure NASA's work focuses on the will of the people, not the political whims of whatever President is in office at the time.

NASA's human exploration program has been through a tumultuous seven years. With a new President to be chosen by the end of this year, we must ensure that there is a constancy of purpose in our planning and a surefooted roadmap in place for the future.

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Chairman BABIN. I now recognize the Ranking Member, the gentlewoman from Maryland, for an opening statement.

Ms. EDWARDS. Good morning, and thank you very much, Mr. Chairman. I want to welcome our distinguished panel this morning.

This truly is my passion. I want to thank Chairman Babin for calling the hearing. I think it's really important, and when I look at the young people out here, not only is it my passion but it really is your future, and so I think the work that we have to do today is incredibly important.

Each time we hold hearings on sending humans to Mars, my colleagues and I don't just leave the room, although today I will have to leave a little bit early. We don't leave the subject behind, and I think that that is meaningful for the American people. Instead, we leave with increased determination to help find a way to get there as soon and as safely as possible. I want the American people to share the collective excitement in this room and to embrace the desire to send human explorers farther into space than ever before.

This Committee's inquiries during recent hearings have focused on the need for a clearly articulated plan and next steps, such as the Human Exploration Roadmap that the bipartisan, overwhelmingly bipartisan House-passed NASA Authorization Act of 2015 directs NASA to develop. It took a lot of work for all of us to come together as Republicans and Democrats to embrace that roadmap. I recognize that it's not an easy task given previous flat funding levels, uncertainty over future budgets, and the need to allow flexibility in planning a multi-decadal endeavor.

I also acknowledge that NASA has established a strategy for achieving the goal and an evolvable Mars Campaign that will allow for flexibility in its decisions and that can take advantage of new knowledge and advances in technology. But facets of that strategy, quite frankly, are not detailed enough to inform mission planning and sequencing. That strategy cannot answer questions about whether going to the lunar surface or an asteroid is needed to reduce risk before sending humans to Mars, nor does it allow us to assess whether NASA's approach achieves the right balance of flexibility and definition.

The Congressionally mandated National Academies report, Pathways to Exploration, recommends that NASA follow a pathway, a specific sequence of intermediate accomplishments and destinations that advance the technologies needed to reach the horizon goal, which they conclude is Mars.

The NASA Advisory Council in its December 3rd, 2015, recommendations to the Administrator said that they were pleased that NASA was providing new information about its human exploration architecture. However, they also recommended that "In preparation for the 2017 transition of Administrations NASA further develop their plan for future Human Exploration." Well, this is because of the importance of defining a baseline architecture and plan that encompasses the entire human exploration program.

Mr. Chairman, I'm confident that a plan of sufficient detail can come to fruition, but we don't have time to spare if we're to sustain a challenging endeavor across the upcoming Presidential transition. Now it's the time for us to get rid of the politics and actually

match our goals with a plan, and without agreement on the substance of a plan, the path forward is less clear and the sustainability of progress toward the Mars goal is left vulnerable to rehashing of interim destinations or even redirection. We've seen that happen in the past. This last decade, despite the concerns articulated by the Chairman, this last decade has been fraught with confusion, both from the Congress, Republicans and Democrats, and Republican and Democratic Presidents, and it's time to put that aside so that we can advance the science that's necessary.

And, make no mistake, we have to do our jobs here in Congress and we have to be of a mind in providing NASA with the necessary resources and budgetary stability to carry out such a plan. The Congress's recent increase in appropriations for fiscal year 2016 for NASA's exploration systems is a good start, but they need to be sustained and built upon if we're to reach that goal.

So Mr. Chairman, we have a lot to discuss this morning, and I look forward to our witnesses' testimony, and what I would urge us to do is, again, let's just put the politics aside. I agree with the Chairman that going to space is not about Republicans and Democrats, and when I look at these young people out here and I see your future and I see the challenge that you're going to take on, you don't care whether it's a D or an R. We care that we advance the science to get us to our goal, and I look forward to doing that.

Thank you, Mr. Chairman, and I yield.

[The prepared statement of Ms. Edwards follows:]

OPENING STATEMENT
Ranking Member Donna F. Edwards (D-MD)

House Committee on Science, Space, and Technology
Subcommittee on Space
"*Charting a Course: Expert Perspectives on Human Exploration Proposals*"
February 3, 2016

Good morning, and welcome to our distinguished panel of witnesses. I want to thank Chairman Babin for calling this hearing titled "*Charting a Course: Expert Perspectives on Human Exploration Proposals*".

This is my passion. Each time we hold hearings on sending humans to Mars, my colleagues and I don't just exit the room and leave the subject behind. Instead, we leave with increased determination to help find a way to get there as soon as is safely possible.
I want the American people to share our excitement and desire to send human explorers farther into space than ever before.

This Committee's inquiries during recent hearings have focused on the need for a clearly articulated plan and next steps, such as the Human Exploration Roadmap that the bipartisan, House-passed NASA Authorization Act of 2015 directs NASA to develop.
I recognize that this is not an easy task given previous flat funding levels, uncertainty over future budgets, and the need to allow flexibility in planning a multi-decadal endeavor.
I also acknowledge that NASA has established a strategy for achieving the goal and an Evolvable Mars Campaign that will allow for flexibility in its decisions and that can take advantage of new knowledge and advances in technology.

But facets of that strategy are not detailed enough to inform mission planning and sequencing. That strategy cannot answer questions about whether going to the lunar surface or an asteroid is needed to reduce risk before sending humans to Mars. Nor does it allow us to assess whether NASA's approach achieves the right balance of flexibility and definition.

The Congressionally-mandated National Academies report, *Pathways to Exploration,* recommends that NASA follow a pathway—a specific sequence of intermediate accomplishments and destinations that advance the technologies needed to reach the horizon goal, which they conclude is Mars.

The NASA Advisory Council in its December 3rd 2015 recommendations to the Administrator said they were pleased that NASA was providing new information about its human exploration architecture. However, they also recommended that "*In preparation for the 2017 transition of Administrations…NASA further develop their plan for future Human Exploration*" because of the importance of defining a baseline architecture and plan that encompasses the entire human exploration program.

Mr. Chairman, I'm confident that a plan of sufficient detail can come to fruition, but we don't have time to spare if we are to sustain such a challenging endeavor across the upcoming Presidential transition. Without agreement on the substance of a plan, the path forward is less clear and the sustainability of progress toward the Mars goal is left vulnerable to rehashing of interim destinations or even redirection. And, make no mistake, we need to do <u>our</u> jobs in providing NASA with the necessary resources and budgetary stability to carry out such a plan. The Congress's recent increase in appropriations for Fiscal Year 2016 for NASA's exploration systems is a good start, but they need to be sustained.

Well, Mr. Chairman, we have a lot to discuss this morning, and I look forward to our witness' testimony. Thank you, and I yield back the balance of my time.

Chairman BABIN. Thank you, Ms. Edwards. I appreciate those words. And I also would like to welcome all you young folks out there as well as you not-so-young folks. Are you all from Florida? Yes. Thank you for being here this morning. Louisiana? Okay. Well, that's good. Almost to Texas.

And speaking of Texas, I now recognize the Chairman of the full Committee from the great State of Texas, Chairman Lamar Smith.

Chairman SMITH. Thank you, Mr. Chairman.

Americans are fascinated by space exploration. It fuels our desire to push the boundaries of what is possible and to reach beyond our own pale blue dot.

In the last few years, the flagship deep space exploration programs at NASA, both robotic and human, have been under attack by the Obama Administration. This Administration cancelled the robotic ExoMars mission and the Constellation program, and it continues to propose drastic cuts to the Space Launch System and Orion programs. These programs were all developed to support deep space exploration to destinations like the Moon and Mars. The Obama Administration cannot claim that it prioritizes Mars exploration if it refuses to prioritize and support the programs that will get us there, and the budget instability created by the Administration makes it hard for NASA to plan and execute critical programs. For example, NASA recently announced that the first crewed mission for SLS and Orion was delayed by two years because the Administration would not allow NASA to budget for the programs.

While the Administration regularly cuts SLS and Orion budget requests, Congress continues to restore those cuts in a bipartisan fashion, and there is bipartisan support within Congress for SLS and the Orion crew vehicle. This Committee has restored proposed cuts year after year in our authorization bills, and the House and the Senate Appropriations Committees restored funding for the SLS and Orion at the levels necessary to keep their development on track.

The SLS and Orion programs represent what is most impressive about the American spirit: the desire to explore. The technologies that are developed for these programs exemplify our greatest breakthroughs and demonstrate American ingenuity. This Committee will not permit this Administration to threaten the succession of these programs. Any efforts to cancel these programs will be met with stiff opposition.

The Administration should develop solid plans for future exploration missions that foster support from the science and engineering communities. However, the Administration continues to push plans for an uninspiring and unjustified Asteroid Retrieval Mission. Just last week, NASA announced its strategy to develop the spacecraft bus that will be used for the robotic elements of that mission. The Administration continues to force this mission on NASA without any connection to a larger exploration roadmap and absent support from the scientific community or NASA's own advisory committees. This is a misguided mission without a budget, without a launch date, and without ties to exploration goals. It is a mission without the support necessary to make it a reality in the nine months remaining in the Obama Administration. It is just a

time-wasting distraction but maybe that is what the Administration really wants.

Instead, the Administration should follow the advice of the NASA Advisory Council and more fully develop its human exploration plans, including a human flyby mission to orbit Mars. There are many options, but without a roadmap to guide the agency, NASA will continue to be subject to indirection and proposed budget cuts by the White House. For its part, Congress will continue to ensure that space exploration will receive the funding needed to stay on schedule and on budget.

Great nations do great things. Fortune favors the bold. These next few years are critical. A trip to Mars can turn science fiction into science fact before our eyes and within our lifetime. The first flag to fly on the surface of Mars should be ours. I hope the Administration will join Congress in pursuing that goal.

Thank you, Mr. Chairman. I yield back.

[The prepared statement of Chairman Smith follows:]

COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Lamar Smith, Chairman

For Immediate Release
February 3, 2016

Media Contact: Laura Crist
(202) 225-6371

Statement of Chairman Lamar Smith (R-Texas)

Charting a Course: Expert Perspectives on NASA's Human Exploration Proposals

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This administration cancelled the robotic ExoMars mission and the Constellation program, and it continues to propose drastic cuts to the Space Launch System (SLS) and Orion programs.

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For its part, Congress will continue to ensure that space exploration will receive the funding needed to stay on schedule and on budget.

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The first flag to fly on the surface of Mars should be ours. I hope the administration will join Congress in pursuing that goal.

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Chairman BABIN. Thank you, Mr. Chairman. I appreciate those wise words.

Now I recognize the Ranking Member of the full Committee, another person from Texas, Ms. Johnson.

Ms. JOHNSON. Thank you very much, Mr. Chairman, and good morning to all, and let me welcome our distinguished panel, and welcome our young people.

I have made it well known that I consider NASA to be a critical national asset. NASA is a source of technological and scientific innovation, an inspiration to generations of young people, and a catalyst for economic growth. It is also a positive symbol of American preeminence worldwide and a demonstration of our commitment to international cooperation in the peaceful uses of outer space.

Human exploration is a highly visible facet of NASA's multi-mission portfolio. It is thus appropriate to continue to examine the nation's human exploration strategy.

At a June 2014 Committee hearing, we heard from the co-chairs of the National Academies' review of the future of human exploration in the United States. That comprehensive review was conducted at Congress's direction. As I said at that time of the hearing, the Academies report did not mince words. It provided us with an important wake-up call. The report's conclusions were clear. We are not going to have a human space exploration program worthy of this great nation if we continue down the current path of failing to provide the resources needed to make real progress and failing to embrace clear—a clear goal and a pathway to achieving that goal. It rests with this Committee and Congress, not the White House, on what is authorized and what is appropriated in this Congress.

What we need now is a clearly articulated plan on how we will get to Mars and what we called a roadmap in the House-passed 2015 NASA Reauthorization Act and what the Academies called a pathway in their report.

In just about one year, the nation will transition to a new Presidential Administration. Such transitions have, in the past, led to significant redirections in NASA's human exploration programs. Mr. Chairman, if that were to happen again, that would be a tragedy, and a wasteful one at that. It is Congress's responsibility to listen to the reports and make recommendations and authorizations accordingly.

NASA has made significant progress since 2010 NASA reauthorization—Authorization Act was enacted. Fabrication of the Space Launch System is underway, flight testing of the Orion vehicle is confirming design objectives, ground systems are being modernized, and ways of mitigating the effects of long-term space travel are the subject of intense research on the International Space Station. In that regard, Mr. Chairman, I hope we can have an opportunity to hear from NASA, in the not-too-distant future, on the progress of its journey to Mars strategy and how investments in SLS, Orion, and ISS fit into that strategy.

In conclusion, last week we honored the crews of Apollo-1, STS–51L, and STS–107. These brave men and women paid the ultimate price while furthering the cause of exploration and discovery. We as a nation owe it to them to continue this grand journey of explo-

ration of the Universe. Future generations of Americans depend on us. We cannot blame anybody else but us. We must not let the nation down. We must not let our young people down.

I thank you, and yield back.

[The prepared statement of Ms. Johnson follows:]

OPENING STATEMENT
Ranking Member Eddie Bernice Johnson (D-TX)

House Committee on Science, Space, and Technology
Subcommittee on Space
"*Charting a Course: Expert Perspectives on Human Exploration Proposals*"
February 3, 2016

Good morning. And welcome to our distinguished panel.

I have made it well known that I consider NASA to be a critical national asset. NASA is a source of technological and scientific innovation, an inspiration to generations of young people, and a catalyst for economic growth.

It is also a positive symbol of American preeminence worldwide and a demonstration of our commitment to international cooperation in the peaceful uses of outer space. Human exploration is a highly visible facet of NASA's multi-mission portfolio.

It is thus appropriate to continue the Committee's examination of the Nation's human exploration strategy. At a June 2014 Committee hearing, we heard from the co-chairs of the National Academies' review of the future of human space exploration in the United States. That comprehensive review was conducted at Congress's direction.

As I said at the time of the hearing, the Academies report did not mince words. It provided us with an important "wake-up call". The report's conclusions were clear. We are not going to have a human space exploration program worthy of this great Nation if we continue down the current path of failing to provide the resources needed to make real progress and failing to embrace a clear goal and pathway to achieving that goal.

What we need <u>now</u> is a clearly articulated plan on how we will get to Mars--what we called a *Roadmap* in the House-passed 2015 NASA Authorization Act and what the Academies called a *Pathway* in their report.

In just about one year, the Nation will transition to a new Presidential Administration. Such transitions have, in the past, led to significant redirections in NASA's human exploration programs. Mr. Chairman, if that were to happen again, that would be a tragedy, and a wasteful one at that.

NASA has made significant progress since the 2010 NASA Authorization Act was enacted. Fabrication of the Space launch System is underway, flight testing of the Orion vehicle is confirming design objectives, ground systems are being modernized, and ways of mitigating the effects of long term space travel are the subject of intense research on the ISS.

In that regard, Mr. Chairman, I hope we have an opportunity to hear from NASA, in the not too distant future, on the progress of its Journey to Mars strategy and how investments in SLS, Orion, and ISS fit into that strategy.

In conclusion, last week we honored the crews of Apollo-1, STS-51L, and STS-107. These brave men and women paid the ultimate price while furthering the cause of exploration and discovery.

We, as a Nation, owe it to them to continue this grand journey of exploration of the Universe. Future generations of Americans depend on us. We must not let them down.

Chairman BABIN. Thank you, Ranking Member Johnson.

Now let me introduce our worthy and expert witnesses at this time. Mr. Tom Young, former Director of NASA's Goddard Space Flight Center, former President and Chief Operating Officer of Martin Marietta Corporation, and former Chairman of SAIC. Mr. Young joined NASA in 1961 as a member of the Lunar Orbiter Project Team and was Mission Director for the program Viking. Prior to being named Director of Goddard Space Flight Center, Mr. Young was Director of the Planetary Program at NASA headquarters and Deputy Director of the Ames Research Center. 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 master's of management degree from MIT.

Dr. John Sommerer is our second witness. Dr. Sommerer is a Technologist with over 35 years of professional experience and over 20 years of executive experience. He chaired the Technical Panel of the Pathways to Exploration report at the National Academy of Sciences. Dr. Sommerer received his B.S. and M.D. degrees in system science and mathematics from Washington University in St. Louis, an M.D. in applied physics from Johns Hopkins University, and his Ph.D. in physics from the University of Maryland.

Dr. Spudis is our final witness today. Dr. Paul Spudis is a Senior Staff scientist at the Lunar and Planetary Institute in Houston, Texas. At LPI, Dr. Spudis's research focuses on the geological processes of the terrestrial planets and the study of the requirements for sustainable human presence on the Moon. He is the recipient of numerous awards and has authored or co-authored over 100 scientific papers and seven books. Dr. Spudis received his B.S. and his Ph.D. from Arizona State University and his master of science from Brown University.

I want to tell you how appreciative we are that you three illustrious gentlemen have come to speak with us today.

I would now like to recognize Mr. Young for five minutes to present his testimony.

TESTIMONY OF MR. TOM YOUNG, FORMER DIRECTOR, GODDARD SPACE FLIGHT CENTER, NASA; FORMER PRESIDENT AND CHIEF OPERATING OFFICER, MARTIN MARIETTA CORPORATION

Mr. YOUNG. Chairman Babin, Ranking Member Edwards, and Committee members, I'm pleased to have the opportunity to present my views on the United States' human spaceflight program. While I'm a member of the NASA Advisory Council, my participation in the hearing today is as an individual representing only myself.

The United States human spaceflight program from Alan Shepherd's initial suborbital flight and John Glenn's orbital flight to today's International Space Station has been rich in exploration excitement, scientific return and technological accomplishments.

The success of the human spaceflight program for over five decades can be traced to many factors. Clearly the integration of the

extraordinary NASA capabilities with the exceptional implementation capabilities of industry has been a major factor. NASA alone or industry alone could not have been successful. This is an important lesson as we plan for the future.

Today the future of the human spaceflight program is far from clear. We know some critical parts of the puzzle, including the ISS, Commercial Cargo, Commercial Crew, SLS and Orion. There are many pieces that are yet to be defined and funded. These include a habitat module, landing systems, a solar electric propulsion tug, and a launch system for return from the surface of the Moon or Mars. We have continual debate as to whether our goal should be the Moon, Mars or both.

We have a 2016 budget that allocates approximately $9 billion for human spaceflight. The budget is divided roughly equal between LEO and exploration. What we do not have is a plan, strategy, or architecture with sufficient detail that takes us from today to humans on the surface of Mars or the Moon with a long-term goal of extended presence.

I would like to offer my views on the existing and missing pieces of the puzzle, starting with the budget. If the 2016 amount of $9 billion remains constant with the addition of inflation for the next two decades, there will be approximately $180 billion with today's buying power available. With that level of funding, significant progress can be made on a human exploration program.

A study to define minimal architecture for human journeys to Mars initiated by Scott Hubbard and conducted at the Jet Propulsion Laboratory provides a credible argument that a Mars mission is feasible at these funding levels. I personally believe increases in the budget will be necessary to support a comprehensive program that includes appropriate precursor activities and missions to realize a responsible funding level for exploration. It's necessary also to make decisions between low-Earth orbit and activities in low-Earth orbit and to have a well-defined, highly focused plan that includes only those activities necessary for the success of the endeavor.

Currently the human spaceflight budget supports both a LEO program consisting of ISS, Commercial Cargo and Commercial Crew and an exploration program consisting of SLS, Orion, and other exploration activities. Future budgets will be required to support the additional required pieces of the puzzle that I discussed earlier. The combination of the current LEO program and the desired exploration program are not affordable at current budget levels. A choice is required between the two programs.

A sustainable exploration program requires that the necessary knowledge from ISS be obtained expeditiously followed by diverting current ISS funds to exploration. An alternative is to continue funding the LEO program and forego a credible Moon or Mars exploration program that results in humans on the surface within a reasonable schedule and budget. We cannot do both without a major augmentation of the budget.

NASA has done an excellent job of maintaining a conservative cargo transportation capability. This conservative approach allows a mission failure or multiple failures to occur without catastrophic

consequences. It also allows a management approach that relies heavily on the commercial partner with modest NASA involvement.

Commercial Crew is much more challenging. A Commercial Crew failure that involves loss of the crew will be a catastrophe. This recognition requires Commercial Crew to be managed significantly differently than Cargo. Commercial Crew requires the full application of the NASA human spaceflight expertise in combination with the extraordinary implementation capability of industry to assure an acceptable probability of success. The concept often stated to let the commercial world be responsible for LEO activities with NASA responsible for exploration is not valid for Commercial Crew.

The next topic I would like to address is the Moon-Mars debate. Each option has merit. While a human to the Moon program is highly challenging, a human to Mars program is much more difficult, challenging and costly. This latter factor must be taken into consideration in the debate. My opinion is that Mars is a much more compelling option. I believe NASA, the current Administration and the House in the NASA Authorization Act of 2014 and 2015 have settled upon the human to Mars option. It is clear again that we cannot do both and there is a need to focus all attention, capabilities and resources upon one option.

For the remainder of my comments, I assume the humans to the surface of Mars option to be the choice. In my view, a plan is required for the following reasons. One: A plan is required for the implementation team to have a common focus. A plan is necessary to obtain program support. Without a plan, constituents cannot make an evaluation and know if they are supportive. A new Administration will be in place in about a year. Without a plan it will be difficult to obtain support and avoid another redo of the content and focus of the United States human spaceflight program. A plan is necessary to effectively define required technologies, including the level and schedule. A plan is necessary to effectively define supporting information needed from ISS and the NASA science program. A plan is necessary to identify the approximate level of required resources. A plan is necessary to assure resources are applied in the most effective manner. A plan is necessary to define precursor missions that should be planned and implemented. A plan is necessary to define the cislunar space/proving ground activity that is currently evolving. It is important to do what is required for a successful exploration program and not what is possible. A plan is necessary to effectively assess risk and develop mitigation plans.

An argument against a plan at the current time is that we are not ready to finalize the necessary elements of the plan. I believe a strength of NASA program management is to establish a plan relatively early with the recognition that as new information becomes available, the plan can be changed. I believe we have the opportunity to set a direction for the United States human exploration program that is exciting, realistic, inspiring, and sustainable. I believe the most compelling case is for the humans to the surface of Mars option.

Decisions are required relative to LEO if a vigorous exploration program is to be pursued. This includes the future of ISS and Commercial Crew. Preparation is required for the transition to the new

Administration. A plan in sufficient detail to maximize the probability of support and sustainability is required. Above all else, a plan with significant detail that takes us from today to humans on the surface of Mars is required.

Thank you.

[The prepared statement of Mr. Young follows:]

TESTIMONY TO THE COMMITTEE

ON

SCIENCE, SPACE AND TECHNOLOGY

SUBCOMMITTEE ON SPACE

FEBRUARY 3, 2016

A. THOMAS YOUNG

Chairman Babin, Ranking Member Edwards and Committee members, I am pleased to have the opportunity to present my views on the U. S. human spaceflight program. While I am a member of the NASA Advisory Council, my participation in the hearing today is as an individual representing only myself.

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The success of the human spaceflight program for over five decades can be traced to many factors. Clearly the integration of the extraordinary NASA capabilities with the exceptional implementation capabilities of industry has been a major factor. NASA alone or industry alone could not have been successful. This is an important lesson as we plan for the future.

Today the future of the human spaceflight program is far from clear. We know some critical parts of the puzzle , including the ISS, Commercial Cargo, Commercial Crew, SLS and Orion. There are many pieces that are yet to be defined and funded. These include a habitat module, landing systems,

a solar electric propulsion tug and a launch system for return from the surface of the moon or Mars.

We have continual debate as to whether our goal should be the moon, Mars or both.

We have a FY 2016 budget that allocates approximately 9B$ for human spaceflight. The budget is divided roughly equal between LEO and exploration.

What we do not have is a plan, strategy, or architecture with sufficient detail that takes us from today to humans on the surface of Mars or the moon with a long term goal of extended presence.

I would like to offer my views on the existing and missing pieces of the puzzle. Starting with the budget , if the FY 2016 amount of 9B$ remains constant with the addition of inflation for the next two decades there will be approximately 180B$ with today's buying power available. With that level of funding, significant progress can be made on a human exploration program. A study to define a minimal architecture for human journeys to Mars initiated by Scott Hubbard and conducted at the Jet Propulsion Laboratory provides a credible argument that a Mars mission is feasible at these funding levels. I believe Increases in the budget can be expected to support a comprehensive program that includes appropriate precursor activities and missions. To realize a responsible funding level

for exploration will require critical decisions as to the activities in Low Earth Orbit (LEO) and a well defined, highly focused plan that includes only those activities necessary for the success of the endeavor.

Currently the human spaceflight budget supports both a LEO program consisting of ISS, Commercial Cargo and Commercial Crew and an exploration program consisting of SLS, Orion and other exploration activities. Future budgets will be required to support the additional required pieces of the puzzle discussed earlier. The combination of the current LEO program and the desired exploration program are not affordable at current budget levels. A choice is required between the two programs. A sustainable exploration program requires that the necessary knowledge from ISS be obtained expeditiously followed by diverting current ISS funds to exploration. An alternative is to continue funding the LEO program and forgo a credible moon or Mars exploration program that results in humans on the surface within a reasonable schedule and budget. We cannot do both without a major augmentation of the budget.

NASA has done an excellent job of maintaining a conservative cargo transportation capability. This conservative approach allows a mission failure or multiple failures to occur without catastrophic consequences. It also allows a

management approach that relies heavily on the commercial partner with modest NASA involvement.

Commercial Crew is much more challenging. A Commercial Crew failure that involves loss of the crew will be a catastrophe. This recognition requires Commercial Crew to be managed significantly differently than Cargo. Commercial Crew requires the full application of the NASA human spaceflight expertise in combination with the extraordinary implementation capability of industry to assure an acceptable probability of success. The concept often stated to let the "commercial world" be responsible for LEO activities with NASA responsible for exploration is not valid for Commercial Crew.

If the emphasis is to be on exploration as opposed to ISS, it seems prudent to reexamine the economics to NASA of Commercial Crew. A counter argument is that a vibrant commercial enterprise will emerge in LEO after NASA "leaves." Hopefully, this is true. I am not convinced; however, if the commercial sector believes this to be true and a good investment, than it should be funded by the commercial sector and not at the expense of the exploration program.

The next topic I would like to address is the moon-Mars debate. Each option has merit. While a human to the moon program is highly challenging, a human to Mars program is much more difficult, challenging and costly. This later factor

must be taken into consideration in the debate. My opinion is that Mars is a much more compelling option. I believe NASA, the current Administration and the House in the NASA Authorization Act of 2014 and 2015 have settled upon the human to Mars option. It is clear that we cannot do both and there is a need to focus all attention, capabilities and resources upon one option. For the remainder of my comments, I assume the humans to the surface of Mars option to be the choice.

The next subject addresses a critical missing piece of the puzzle. There is no obvious plan, strategy or architecture in significant detail for the future exploration program. I use the terms plan, strategy or architecture because the choice of the words in themselves seem to be polarizing. I am going to use the most general term, plan.

In my view a plan is required for the following reasons and must contain sufficient detail to accomplish the objective stated in each reason.

1) A plan is required for the implementation team to have a common focus.

2) A plan is necessary to obtain program support. Without a plan, constituents cannot make an evaluation and know if they are supportive.

3) A new administration will be in place in about a year. Without a plan it will be difficult to obtain support and avoid another redo of the content and focus of the U. S. human spaceflight program.

4) A plan is necessary to effectively define required technologies, including the level and schedule.

5) A plan is necessary to effectively define supporting information needed from ISS and the NASA science program.

6) A plan is necessary to identify the approximate level of required resources.

7) A plan is necessary to assure resources are applied in the most effective manner.

8) A plan is necessary to define precursor missions that should be planned and implemented.

9) A plan is necessary to define the cislunar space/proving ground activity that is currently evolving. It is important to do what is required for a successful exploration program and not what is possible.

10) A plan is necessary to effectively assess risk and develop mitigation plans.

An argument against a plan at the current time is that we are not ready to finalize the necessary elements of the plan. I

believe a strength of NASA program management is to establish a plan relatively early with the recognition that as new information becomes available, the plan can be changed.

I believe we have an opportunity to set a direction for the U. S. human exploration program that is exciting, realistic, inspiring and sustainable. I believe the most compelling case is for the humans to the surface of mars option.

Decisions are required relative to LEO if a vigorous exploration program is to be pursued This includes the future of ISS and Commercial Crew.

Preparation is required for the transition to the new administration. A plan in sufficient detail to maximize the probability of support and sustainability is required.

Above all else, a plan with significant detail that takes us from today to humans on the surface of Mars 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 Program Viking. 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 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 an honorary doctor of science degree from Salisbury State University.

Chairman BABIN. Thank you. Thank you very much, Mr. Young.

I now recognize Dr. Sommerer for five minutes to present his testimony.

TESTIMONY OF DR. JOHN C. SOMMERER,
CHAIR, TECHNICAL PANEL,
PATHWAYS TO EXPLORATION REPORT,
NATIONAL ACADEMY OF SCIENCES

Dr. SOMMERER. Chairman Babin, Ranking Member Edwards, and distinguished Members of the Subcommittee, thank you for the opportunity to discuss the options for architectures and intermediate steps to develop the capability to send humans to Mars while maintaining constancy of purpose through the next and necessarily many subsequent Administrations.

I had the privilege of chairing the Technical Panel of the congressionally mandated National Research Council Committee on Human Spaceflight, and I'm here to represent some 1 of the salient features of the salient features of that panel's conclusions about possible pathways to Mars, as well as some of my own views.

The first, and by far most significant conclusion is that while sending humans to Mars, and returning them safely to Earth, may be technically feasible, it is an extraordinarily challenging goal from physiological, technical, and programmatic standpoints, and because of this extreme difficulty, it is only with unprecedented cumulative investment, and, frankly, unprecedented discipline in development, testing, execution, and leadership, that this enterprise is likely to be successful.

To be explicit and to set the scale of the problem, the Technical Panel, aided by independent cost estimation contractors, and using a process that respected the importance of development risks based on technical challenges, capability gaps, regulatory challenges, and programmatic factors, as well as the need to maintain a reasonable operational tempo, concluded that the first crewed Mars landing might be possible 20 to 40 years from now, after a cumulative expenditure of on the order of half a trillion dollars. The actual time frame and cost will depend greatly on the pathway chosen to achieve the goal, and candidly, the fastest and least expensive pathway that we examined comes with enormous risks to both the success of the missions and the lives of the astronauts conducting them.

Let me briefly and very superficially review the most significant risks of attempting to send humans exploring in deep space. We know that prolonged exposure of astronauts to the space environment has the potential to harm them. Astronauts on long missions such as we're conducting now on ISS and have been conducted by the Soviets in the past with Mir have experienced potentially debilitating effects caused by the microgravity environment. Musculoskeletal deterioration has been best studied, and while exercise has the potential to mitigate its impact, the regimen needed over the long duration of a human mission to Mars may not be realistic.

The radiation environment in space, especially deep space beyond the protection of the Earth's magnetic field, has been quantified largely in terms of increased cancer risk due to galactic cosmos rays, against which shielding is ineffective without prohibitive

mass penalties. However, the non-carcinogenic risks due to radiation such as cumulative neural degeneration are much less well understood and may well prove to be more limiting. It appears that with existing architectures for Mars missions, which include greater-than-1-year stays on the Martian surface, which brings with it its own risks, physiological limits may not be prohibitive, although risks to the astronauts would be very high. Long-duration orbital missions at Mars, or on Mars' moons, may not be feasible at all, because of radiation.

Few of the technological challenges of a crewed Mars mission are insurmountable, but cumulatively, they represent a huge gap relative to our current capabilities and our currently available resources. The Committee's final report includes a list of 15 high-priority technical capabilities, and most of the intersections of those capabilities against the various forms of challenge are red in risk assessment, things such as, there's no technical solution known. There's no such system that's ever been developed at the necessary scale. Current regulations impose significant challenges and will be difficult to change, and development to operational capability is on the order of previous large, national programs. In short, there is an awful lot of technical work to do.

Having spent my life as a technologist, I can say that a large job list isn't altogether a bad thing but it does require a great deal of discipline, and a certain ruthlessness in pruning efforts that are not making needed progress or that don't accumulate to the intended goal. I applaud the fact that, with this Committee's and the Administration—appropriators' help, NASA finally has a Space Technology Mission Directorate, which has recently made some significant contributions to the capabilities that my panel identified as highest priority. However, in other areas that the panel identified as highest priority such as in-space power and propulsion, NASA appears to be maintaining the entire trade space of possible propulsion challenges. SLS and Orion aren't the only things we'll need to get to Mars.

I also wish to note that one of the foundational conclusions of the technical panel is there's a very limited set of places for humans in the solar system for the foreseeable future given what we know about technology and physiology. We've been to the Moon so we know that's possible. We probably can go to some near-Earth asteroids, and as we've discussed already today, maybe we can get to Mars. Given the relative simplicity of the field of regard, there are tremendous technical and programmatic advantages to deciding, once and for all, where we're going, and in what order. Each of these possible destinations has proponents to be what's next, but given the size of the job jar, it's not helpful to keep changing our minds.

The NRC Committee advocated that a defined pathway, with missions to the different possible destinations in sequence has some highly desirable properties such as that the sequence of missions and destinations permits stakeholders to see progress, that the pathway has a logical feed forward of technical capabilities, that the pathway minimizes the use of dead-end systems and equipment, that the pathway is affordable without incurring unac-

ceptable development risk, and the pathway supports, in the context of the available budget, a reasonable operational tempo.

The NRC did not recommend any particular pathway, but did assess three notional pathways against these attributes. The committee noted that the notional pathway that is closest to NASA's current plans has serious deficiencies with regard to the significance of the intermediate destinations, logical feed forward, the number of dead-end systems, and exceedingly high development risk. The committee also noted the two alternative pathways that did not have these efficiencies failed against the affordability and operational tempo attributes at current expenditure levels. To quote the Technical Panel's final briefing to the entire NRC Committee in 2013: "In the current fiscal environment, there are no good pathways to Mars."

So I'd like to conclude briefly with some of my own views. I understand that there is bipartisan support for a "go as we pay" approach to human spaceflight. But just as it is not feasible to take a cross-country trip on a child's allowance, because of threshold costs, we may well never be able to get to Mars at current expenditure levels. It might be better to stop talking about Mars if there is no appetite in Congress and the Administration for higher human spaceflight budgets and no willingness to cut programs that do not contribute to progress. At a minimum, we should agree on a pathway that is satisfying to the public, even if it does not lead to Mars in the foreseeable future. A pathway that includes the surface of the Moon is one obvious possibility.

Thank you.

[The prepared statement of Dr. Sommerer follows:]

Hearing of the House Committee on Science, Space, and Technology
Subcommittee on Space
February 3, 2016
Testimony of Dr. John C. Sommerer
Chair, Technical Panel
NRC Committee on Human Spaceflight

Chairman Babin, Ranking Member Edwards, and distinguished members of the Subcommittee, thank you for the opportunity to discuss the options for architectures and intermediate steps to develop the capabilities and skills necessary to land humans on Mars, while maintaining constancy of purpose through the next, and *necessarily, many subsequent* administrations.

I had the privilege of chairing the Technical Panel of the congressionally mandated National Research Council (NRC[1]) Committee on Human Spaceflight, and I am here to represent some of the salient features of that Panel's conclusions about the possible pathways to Mars, as well as some of my own views. The first, and by far most significant conclusion is that while sending humans to Mars, and returning them safely to the Earth, may be technically feasible, it is an extraordinarily challenging goal, from physiological, technical, and programmatic standpoints. Because of this extreme difficulty, it is only with unprecedented cumulative investment, and, frankly, unprecedented discipline in development, testing, execution, and leadership, that this enterprise is likely to be successful.

To be explicit and to set the scale of the problem, the Technical Panel, aided by independent cost estimation contractors, and using an innovative process that respected the importance of development risks based on technical challenges, capability gaps, regulatory challenges, and programmatic factors, and the need to retain a reasonable operational tempo, concluded that the first crewed Mars landing might be possible 20-40 years from now, after a cumulative expenditure of on the order of half a trillion dollars (constant FY2013 dollars). The actual time frame and cost will depend greatly on the pathway chosen to achieve the goal, and candidly, the fastest and least expensive pathway that we examined comes with enormous risks to both the success of the missions and the lives of the astronauts conducting them.

Let me briefly (and superficially) review the most significant risks of attempting to send humans exploring in deep space.

Human Physiology and Psychology
We know that prolonged exposure of astronauts to the space environment has the potential to harm them. Astronauts on long missions (such as on the ISS and Mir) have experienced potentially debilitating effects caused by the microgravity environment. Musculoskeletal deterioration has been best studied, and while exercise has the potential to mitigate its impact, the regimen needed over the long duration of a human mission to Mars may not be realistic. Much more recently, ocular damage and negative effects on the development of the endothelial cells lining blood vessels have also been discovered.

The radiation environment in space, especially deep space beyond the protection of the Earth's magnetic field, has been quantified largely in terms of increased cancer risk due to galactic cosmic rays, against which shielding is ineffective without prohibitive mass penalties. The non-

[1] The National Research Council is now known as the National Academies of Sciences, Engineering, and Medicine.

carcinogenic risks due to radiation, such as cumulative neural degeneration, are much less well understood and may well prove to be more limiting than carcinogenic effects. It appears that, with existing architectures for Mars missions, which include greater-than-one-year stays on the Martian surface (which itself poses unquantified health risks due to perchlorates and other chemical hazards) physiological limits may not be prohibitive, although risks to the astronauts would be very high. Long duration orbital missions at Mars, or on Mars' moons, may not be feasible at all, because of radiation. And finally, the psycho-social limits on a small group of astronauts confined to extremely tight quarters for multiyear periods, without possibility of real-time interaction with family and friends, pose another poorly understood threat to crew safety and mission success.

Technological Challenges

The NRC Technical Panel included a vast pool of experience in virtually all areas of space technology, and members who were deeply involved in earlier efforts going back to the Apollo, Gemini, and Mercury programs, and others involved in helping to define NASA's current technology roadmaps. Few of the technological challenges of a crewed Mars mission are insurmountable, but cumulatively, they represent a huge gap relative to our current capabilities, and our currently available resources. The Committee's final report includes a list of 15 high-priority technical capabilities needed to get humans to Mars, each assessed against the difficulty of developing the technical capability, the gap between what is needed and current capability, regulatory challenges, and cost & schedule challenges. One can summarize the situation by considering a matrix of the 15 capabilities indexed by the four different types of challenge, resulting in 60 assessments. Eighteen of those intersections are rated "green," meaning that progress can be expected with minimal risk. Twenty-four intersections are rated "yellow," indicating significantly higher risk. Finally, 18 of the intersections are rated "red," indicating such hurdles as "no technical solution known," "no such systems have ever been developed at the necessary scale," "current regulations impose significant challenges and will be difficult to change," and "development to operational capability is on the order of previous large, national programs." In short, there is an awful lot of technical work to do.

Having spent my life as a technologist, I can say that a large job list is not altogether a bad thing. But it does require a great deal of discipline, and a certain ruthlessness in pruning efforts that are not making needed progress. I applaud the fact that, with this Committee's and the Appropriators' help, NASA finally has a Space Technology Mission Directorate, which has recently made some significant contributions to the capabilities that my Panel identified as "highest priority." One of those areas, essential to landing humans on Mars, is "Entry, Descent, and Landing," where the technology developed for the NASA Curiosity robotic rover currently exploring Mars will not scale to the capabilities needed to land astronauts. STMD in 2015 successfully tested the Low Density Supersonic Decelerator, using the Earth's upper atmosphere as a surrogate for Mars' thin atmosphere to investigate one of many possible approaches to decelerate astronauts to a safe landing on Mars.

However, in other areas that the Panel identified as "highest priority," such as "In-space Power and Propulsion," NASA appears to be maintaining the entire trade-space of possible propulsion technology in a diffuse, subcritical approach to one of the chief challenges. Certainly, the SLS is a big-ticket item that is one of many chemical propulsion concepts that could launch components of a Mars mission for assembly in Low Earth Orbit. There are also much smaller

efforts consuming resources on Nuclear Thermal Propulsion (viewed by many members of our Panel as essential to getting to Mars), long-term cryogenic storage (suggesting that NASA intends Mars missions to be chemically propelled through deep space), and electric propulsion intended for use in the Asteroid Redirect Mission, which, in my opinion, serves no useful purpose in developing the capability to send humans to Mars. (A high-capability ion thruster, however, could be extremely enabling for robotic planetary exploration.) This leads to what is probably the most important conclusion of the Human Spaceflight Committee, the importance of establishing a Pathway for human exploration of deep space.

Pathways for Human Exploration

As context for this portion of my testimony, I wish to note for the Subcommittee that one of the Technical Panel's earliest, and foundational conclusions is that there is a very limited set of potential destinations for humans in the solar system, given what we know about technology, its likely future, and human physiology. (Most of us are science fiction fans, and optimists, so we don't mean to imply that people won't go farther, ever. But for this study, the ground rules were set by Congress in the 2010 NASA Authorization bill. We were to look toward a foreseeable future, where it made sense for the United States to have concrete plans. As it was, we exceeded the mandated time constraints, to make clear the extreme difficulty and expense of human missions to deep space.)

We've been to the Moon, so we know that's possible. We probably can go to some near-earth asteroids, and, as we've discussed earlier today, maybe we can get to Mars. That's it (ignoring some uninspiring missions to special "points in space" that in my view lack intrinsic interest). Given the relative simplicity of the field of regard, there are tremendous technical and programmatic advantages to deciding, once and for all, where we're going, and in what order. Each of these possible destinations has proponents to be "what's next," as we've already heard today. But, given the size of the job jar, it's not helpful to keep changing our minds. The NRC Committee advocated, and many of us still advocate, a defined "Pathway," with missions to the different possible destinations in a sequence that has some highly desirable properties, and not deviating from that Pathway unless we run into an insurmountable obstacle, such as new information on the space environment, the limits of human physiology, or national solvency. A desirable pathway has six critical attributes:

1) The final (horizon) and intermediate destinations have profound scientific, cultural, economic, inspirational, and/or geopolitical benefits that justify public investment.
2) The sequence of missions and destinations permits stakeholders, including taxpayers, to see progress and develop confidence in NASA's and national leadership's ability to execute the pathway.
3) The pathway has a logical feed-forward of technical capabilities.
4) The pathway minimizes the use of dead-end equipment and capabilities that do not contribute to later destinations on the pathway.
5) The pathway is affordable without incurring unacceptable development risk. And,
6) The pathway supports, in the context of the available budget, an operational tempo that ensures retention of critical technical capability, proficiency of operators, and effective use of infrastructure.

The NRC Committee did not recommend any particular pathway, but did assess three notional pathways against these attributes, and against the technology and human physiology constraints that apply. The NRC Committee noted that the notional pathway that is closest to

NASA's current plans, has serious deficiencies with regard to the significance of intermediate destinations, logical feed-forward, dead-end systems, and exceedingly high development risk. The NRC Committee also noted that two alternative pathways that did not have these deficiencies failed against the affordability and operational tempo attributes at current expenditure levels. To quote the Technical Panel's final briefing to the entire NRC Committee in 2013, "In the current fiscal environment, there are no good pathways to Mars."

I would like to conclude with some of my own views. I understand that there is bipartisan support for a "go as we pay," approach to human spaceflight. But, just as it is not feasible to take a cross-country trip on a child's allowance, because of threshold costs, we may well never be able to get to Mars at current expenditure levels. It might be better to stop talking about Mars if there is no appetite in Congress and the Administration for higher human spaceflight budgets, and more disciplined execution by NASA. (And further relative reductions of NASA's science budgets are neither a plausible answer, nor responsible, given the fact that the findings from the Earth Science, Planetary Science, and Heliophysics programs offer far more practical benefit to humanity than does a program of human exploration, especially one that does not show significant progress relative to what we have seen before). At a minimum, we should agree on a pathway that is satisfying to the public, even if it does not lead to Mars in the foreseeable future. A pathway that includes the surface of the Moon is one obvious possibility.

Thank you for your attention, and I would be happy to answer any questions.

Narrative Biography, John C. Sommerer, Ph.D.

John C. Sommerer is a technologist with over 35 years of professional experience and over 20 years of executive experience. He is the principal of Talitha Ventures, which he founded to provide broad-spectrum technology consulting, including unique, transformational investment opportunities. He previously served in a number of senior executive positions at the Johns Hopkins Applied Physics Laboratory (APL), the largest of the Department of Defense University Affiliated Research Centers. In 2011, Dr. Sommerer was designated by Hopkins as one of the inaugural Daniel Coit Gilman Scholars, "exemplifying the highest ideals of the University," and was elected a full (life) member of the International Academy of Astronautics. Until January 1, 2014, he led the APL Space Sector, with responsibility for all APL contributions to military, intelligence community, and civil space programs, including the New Horizons mission to Pluto, the MESSENGER mission to Mercury, the Van Allen Probes operating in the Earth's radiation belts, Solar Probe Plus, the MDA Precision Tracking Space System, ORSTech 1 and 2 as well as numerous other missions in progress. Prior to 2008, he served JHU/APL as Director of Science & Technology, Chief Technology Officer, Director of the Milton S. Eisenhower Research Center, and he led a number of enterprise-level task forces, strategic plans, and other initiatives. Dr. Sommerer received B.S. and M.S. degrees in systems science and mathematics from Washington University in St. Louis, an M.S. in applied physics from Johns Hopkins University, and a Ph.D. in physics from the University of Maryland. Dr. Sommerer has served on a number of advisory bodies for the U.S. government, including terms as chair and vice chair of the Naval Research Advisory Committee, senior technical advisory committee to the Secretary of the Navy, Chief of Naval Operations, and Commandant of the Marine Corps. He has also served on numerous NRC boards and committees, most recently as a member of the Committee on the Assessment of the Governance Structure of the NNSA National Security Laboratories; as a member of the Committee on Human Spaceflight and chair of the study's Technical Panel; and as a member of the Committee on Operational Science and Technology Options for Defeating Improvised Explosive Devices. He was appointed as a National Associate of the NRC in 2008.

Chairman BABIN. Yes, sir. Thank you, Dr. Sommerer. Those are interesting words.

I now recognize Dr. Spudis for five minutes to present his testimony.

TESTIMONY OF DR. PAUL SPUDIS,
SENIOR SCIENTIST,
LUNAR AND PLANETARY INSTITUTE

Dr. SPUDIS. Thank you, Mr. Chairman. I thank the Committee for this opportunity to give you my thoughts on our nation's program for human exploration of space. This testimony is my personal opinion and does not necessarily represent the views of my employer, the University Space Research Association.

America's space program is in disarray. We pretend that we are on a journey to Mars but in fact possess neither the technology nor the economic resources necessary to undertake a human Mars mission now or within the foreseeable future. What we need is a logically arranged set of short-term, realizable space goal that are not only interesting in and of themselves, but whose attainment will build capability in the long term. Whatever goals are selected, significant milestones can be reached on a regular and recurring basis. Only in such a program can progress be mapped and resources allocated accordingly. Thus, any program to extend human reach beyond low-Earth orbit must be incremental, so that each step is small and affordable, yet cumulative, so that the smaller steps integrate into a larger coherent program.

In 2010, the United States abandoned the goal of lunar return set by Vision for Space Exploration. Congress directed the agency to continue building the Orion spacecraft and to develop a new heavy lift launch vehicle, the Space Launch System. As derivatives of the canceled project Constellation, the new systems are optimized for missions to cislunar space, the zone space between low-Earth orbit and the lunar surface. To replace the Moon as a destination, several near-Earth asteroids were examined, which for various reason all were found to be unobtainable. Instead, NASA embraced the idea of bringing a small asteroid back to cislunar space where the Orion spacecraft visited, the so-called Asteroid Retrieval Mission. This idea was neither fully developed conceptually nor vetted through the scientific and engineering advisory structures that we maintain to review and judge mission concept proposals.

As study of the asteroid retrieval concept has proceeded, the planned size of return object has continually decreased. Initially it was planned to return an asteroid about seven meters across. It is currently planned only to return a small one- to two-meter boulder. More than 85 percent of all near-Earth asteroids are ordinary chondrites, a rock type so renowned for its uniformity that it is used as a compositional standard in cosmic chemical studies, and we also possess tons of this material as ordinary chondrites continually fall onto the Earth's surface every day. As a result of limited power and minimal loiter time, the Orion spacecraft does not possess the capabilities necessary to experiment with extracting useful resources from the asteroid. So the Asteroid Retrieval Mission does

not contribute to our learning how to process and use the material resources of space.

The microgravity of the ARM will not prepare us for human operations on the surface of Mars, which has approximately 1/3 the gravity of the Earth. The ARM offers no unique benefits beyond providing a place for Orion to visit. In terms of scientific and operational importance, it is barren of real accomplishment and irrelevant to future deep space human missions.

As for learning how to use space resources, it can only perform rudimentary reconnaissance of the type already accomplished or planned by a variety of robotic missions. Although it is claimed that the ARM develops technology needed for future Mars missions, specifically the High Power Solar Electric Propulsion Unit, missions to cislunar space can develop many of these technologies just as well and at the same time emplace space-based infrastructure for future use.

Cislunar space, the space between Earth and Moon, is home to 95 percent of our scientific, economic and national security assets, satellites upon which we are critically dependent. We can reach these orbital levels with unmanned systems. When a satellite becomes obsolete or stops functioning, the only solution is replacement. If we could move people and machines throughout the various locales of cislunar space, we would be able to emplace, construct, and upgrade and maintain these satellites.

To create this routine access to cislunar space, we should develop a permanent space-faring infrastructure including transport vehicles, staging nodes, deep space habitats, power stations, and fuel depots. In terms of the energy expended, all destinations in cislunar are essentially equal. If we can go to and from the Moon, we can go to and from all of the other localities in cislunar space. Such a system creates not only routine access to the Moon but to all of cislunar space, and it enables human missions to the planets beyond.

To develop the system, it is vital that we learn how to harvest the material and energy resources of space. Such technology allows us to launch only the most technically advanced and critical equipment from the Earth while large-mass, low-information materials such as propellant and life-support consumables can be obtained from local sources. Thanks to a variety of robotic missions over the last decade, we now know that the Moon possesses these resources in abundance. The poles of the Moon contain billions of tons of water. In its liquid form, this can support human life, and when broken into its component hydrogen and oxygen, it is the most powerful chemical rocket propellant known.

The United States thinks of itself as a world leader in space but our current lack of focus and strategic confusion undermine that claim. There is interest from Europe, India, Russia and China in lunar missions. These efforts are not undertaken merely to plant flags on another world but to reap the benefits offered by the exploration and utilization of the Moon. As the world beats a path to the Moon, we stand aside. How can we claim technological and scientific leadership in space when we shy from participation and seek no ownership in this arena of cislunar space?

But there is another dimension to our abdication of leadership. China is rapidly developing the capability to travel throughout, loiter within, and intercept any target in cislunar space. They have also demonstrated advanced anti-satellite warfare capability most notoriously with their interception and destruction of a target satellite in low-Earth orbit in 2007. Future Chinese anti-satellites loitering at an L-point in cislunar space could fly from the vicinity of the Moon down to lower orbits and approach direction that's not normally monitored and disable the satellites of other nations. In such a scenario, we would be left with a decided disadvantage as a result of our lack of commitment to the establishment of a strong national presence in cislunar space.

America is at a critical juncture in the history of its space program. Congressional leadership is needed to set us on the correct strategic path. The development of the Moon and cislunar space answers important national needs. It is an incremental, affordable and useful direction, a sustainable path that creates new capabilities in space faring. A return to the lunar surface allows us to use the enabling asset of the Moon to journey to and explore the planets beyond.

I thank the Committee for its attention, and I welcome your comments and thoughts, and I'm happy to answer any questions you might have.

[The prepared statement of Mr. Spudis follows:]

United States House of Representatives
Committee on Science, Space, and Technology
Subcommittee on Space

Charting a Course:
Expert Perspectives on NASA's Human Exploration Proposals

Testimony submitted by:
Dr. Paul D. Spudis

February 3, 2016

I thank the Chairman and the Committee for this opportunity to give you my thoughts on the nation's program for the human exploration of space. This testimony is my personal opinion and does not necessarily represent the views of my employer, the Universities Space Research Association.

Why are we here today? America's civil space program is in disarray, with many aspirations and hopes but few concrete, realizable plans for future missions or strategic direction. We pretend that we are on a "#JourneytoMars" but in fact, possess neither the technology nor the economic resources necessary to undertake a human Mars mission now or within the foreseeable future. What is needed is a logically arranged set of short-term, realizable space goals – a series of objectives and destinations that are not only interesting in and of themselves, but whose attainment build space faring capability in the long term.

Whatever space destinations and goals are selected, they must be such that significant milestones can be reached on a regular and recurring basis. Such a program is sustainable – progress (or its lack) can be mapped and resources allocated accordingly. Thus, any program to extend human reach beyond low Earth orbit (LEO) must be incremental, so that each step is small and affordable, yet cumulative, so that the smaller steps integrate into a coherent working program.

Demise of the Vision for Space Exploration In 2010, the United States abandoned the strategic goals for space set by Vision for Space Exploration (VSE). The Vision called for the Shuttle to return to flight, the completion of the International Space Station (ISS), the retirement of the Shuttle, a return to the Moon and a human mission to Mars, in that order. Although the first three objectives were met, the elimination of lunar return left a vacuum in space policy that has yet to be filled. The Moon served two primary purposes in the Vision: 1) a return to the Moon allowed us to develop and test the technologies, hardware and procedures needed for future human exploration beyond LEO; and 2) the use of the material and energy resources of the Moon would enable the creation of new spaceflight capabilities. Specifically desired was the harvesting of water from the poles of the Moon to manufacture propellant and life support consumables for human missions to many destinations beyond LEO, including Mars. These goals were not ancillary to the fulfillment of the VSE but rather, a critical part of the logic of the Vision.

After this loss of this strategic direction, we soon realized that few destinations beyond LEO are reachable within reasonable time-scales (decadal) for affordable cost (existing budgets). An attempt to replace the lunar surface with human missions to asteroids quickly faced the reality that given the technology constraints for human spacecraft, few accessible targets exist. Meanwhile, Congress became increasingly concerned that with the retirement of the Space Shuttle, critical national capabilities associated with that launch system were being irretrievably lost (e.g., industrial infrastructure, such as large-scale precision welding of the Shuttle External Tank, and human capital, in the form of highly skilled launch teams). Thus, Congress directed the agency to continue building the Orion spacecraft and to develop a new heavy-lift launch vehicle, the Space Launch System (SLS). The object of this direction was to ensure that we retained the capability to launch the large payloads needed for the fulfillment of human missions into deep space.

Both the Orion spacecraft and SLS rockets (being derivatives of work done previously on the now-defunct Project Constellation) are generic vehicles; they are not designed with a specific mission in mind but rather, aimed at general applicability to human missions beyond LEO. Given that the two systems come from work previously done to support lunar return, it is not surprising that they are optimized for missions to cislunar space, the zone of space between low Earth orbit and the lunar surface (which includes the Sun-Earth L-points, gravity-neutral zones in space about 1.5 million km (930,000 miles) from Earth). Cislunar space has many potential destinations of interest, but except for the lunar surface, it is all empty space. Thus, Orion and SLS – representing a potentially robust cislunar capability – have no place to go.

The Asteroid Retrieval Mission (ARM). Asteroids circle the Sun in orbits independent of Earth and Moon. When planning a mission to an asteroid, one must select a target using fairly stringent constraints, including its distance from the Sun, the inclination of its orbital plane, and the timing between the positions of Earth and asteroid (in both directions). Given these limitations, few asteroids suitable for human exploration can be identified and none of them are very large. With the lunar surface having been ruled off-limits, the problem of identifying cislunar missions became one of finding something for astronauts to do. In 2011, the Keck Institute for Space Studies came up with the idea of bringing a "destination" to cislunar space: find a small asteroid, attach a solar electric propulsion (SEP) module to it, bring it back to cislunar space and place it where it can be reached by the Orion spacecraft. The concept was sketched out in a 50-page report, but the mission was neither fully developed conceptually nor was its value vetted through the scientific advisory structure that we maintain to review and judge mission concept proposals.

Embraced by NASA as the "next step" towards a human Mars mission, the ARM offers few scientific and scant operational benefits. With additional study, the planned size of the returned object has continually decreased: initially, it was planned to return an asteroid about 7 meters across, but it is now planned to return a small 1-2 m boulder. Virtually all asteroids (~85%) are ordinary chondrites, a rock type so renowned for its uniformity that it is used as a compositional standard in cosmochemical studies. Moreover, we already possess (literally) tons of ordinary chondrite meteorites, as they continually fall onto the Earth every day. With limited power and minimal loiter time near the object, the Orion spacecraft does not possess the capabilities necessary to experiment with resource utilization. Thus, the ARM does not contribute to

learning how to process and use the material resources of space. The ARM will be conducted in microgravity and it will not prepare us for human operations on the surface of Mars, where a significant gravity field exists (approximately one-third the gravity of Earth). Although it is claimed that the ARM develops technology needed for future Mars missions, many of its alleged technological benefits (e.g., solar electric propulsion) can be developed just as well by other cislunar missions and at the same time, emplace transportation infrastructure for future use.

The ARM offers no unique benefits beyond providing a place for Orion to visit. In terms of scientific and operational importance, it is barren of real accomplishment and irrelevant to future human deep space missions. And for learning how to use space resources, it can only perform rudimentary reconnaissance of the type already accomplished or planned by a variety of robotic missions, past (e.g., NEAR), present (e.g., Dawn) and future (e.g., OSIRIS-REx).

Cislunar Development – An Alternative to ARM. By focusing on the development of cislunar space, we will build something of utility and lasting value. This zone of space contains more than 95% of all of our scientific, economic and national security satellite assets. Low Earth Orbit (LEO, 160-2000 km or 100-1200 miles) is the home of the ISS and a multitude of scientific and Earth-monitoring satellites. Middle Earth Orbit (MEO, ~2000-35,000 km or 1200-22,000 miles) is where the satellites of the global positioning system (GPS) reside. Geosynchronous orbit (GEO, 36,000 km or 22,500 miles) is the altitude at which one orbit coincides with one rotation of the Earth (so that the satellite appears to stay in one location in the sky); it is prime real estate in space, the location of most of the world's communications and weather satellites. Highly Elliptical Orbits (1000-36,000 km or 600-22,500 miles) are used for various national security missions. Lagrangian points (L-points, 350,000-1,500,000 km or 220,000-930,000 miles) contain few spacecraft at the moment, but are useful locales for loiter/storage and staging nodes for future missions to more distant destinations. Modern technical civilization is critically dependent on the satellite assets deployed throughout cislunar space.

At present, we can reach these various orbital levels only with unmanned systems. When a satellite becomes obsolete or stops functioning, the only solution is replacement. If we could move people and machines throughout the various locales of cislunar space, we would be able to emplace, construct, upgrade and maintain satellites. Large, distributed space systems could be built that would provide complete hemispheric coverage and create virtually unlimited bandwidth for all types of communication devices. To access the various levels of cislunar space, we need to develop a permanent space faring infrastructure, including transport vehicles, staging nodes, deep space habitats, power stations, and fuel depots. In terms of the energy expended, all destinations in cislunar are essentially equal – if we can go to-and-from the Moon, we can go to-and-from all of the other locales in cislunar space. Such a system creates not only routine access to the Moon and to all of cislunar space, but also enables human missions to the planets beyond.

To become space faring, it is vital that we learn the skills necessary to harvest the material and energy resources of space. Such technology allows us to launch only the most technically advanced and critical equipment from the Earth while large-mass, low-information materials (e.g., propellant, life-support consumables) can be obtained from local sources, wherever we are. Thanks to a variety of robotic missions over the last decade, we now know that the Moon

possesses these resources in abundance. The poles of the Moon contain billions of tons of water. In its liquid form, water supports human life and when broken into its component hydrogen and oxygen gas and then liquefied, it becomes the most powerful chemical rocket propellant known.

Within the next decade, near-term activities having long-term significance can be performed in cislunar space through the creation of a permanent, space-based transportation system. Elements of such a system can be delivered with solar electric propulsion vehicles to various locations in cislunar space, including the L-points. An example of a simple (but extremely useful) technology development mission would be to launch several tons of water from Earth and experiment with transforming and using it for various applications in space. Rechargeable fuel cells combine gaseous hydrogen and oxygen into water, generating electricity; this process makes water, that can be then cracked back into its elemental form using electricity generated by solar panels. By generating solar power at the highly illuminated peaks near the poles and then using the fuel cells to generate power during eclipse, the development of this technology will permit us to stay for extended times on the surface of the Moon. Radiation shielding, a critical requirement to keep crews safe from cosmic rays and solar particle events during months-long, interplanetary voyages, is another important use of water in space. Experimentation with water in deep space prepares us to handle and utilize the water produced in the future from extraterrestrial sources (e.g., lunar polar ice, the hydrated minerals of asteroids, and martian ground ice).

American Leadership in Space. With considerable justification, the United States thinks of itself as a world leader in space. But the current lack of focus and strategic confusion in our civil space program undermine that claim. News coverage of recent and planned space efforts documents a worldwide interest in the Moon, with specific lunar surface mission plans and programs announced by Europe, India, Russia and China. These missions are not being undertaken to merely plant flags on another world, but to reap all of the benefits offered by the exploration and utilization of the Moon. As the world beats a path to the Moon, we stand aside. How can we claim leadership in a technological and scientific movement in which we have no participation and seek no ownership?

There is another dimension to the abdication of our leadership in space. China is rapidly developing the capability to access and use all regions of cislunar space. The Chang'E-2 spacecraft first went into lunar orbit in 2010 and mapped the entire surface over the course of a year. It then left lunar orbit and traveled to Earth-Moon L-2 (a point 60,000 km (37,000 miles) above the center of the lunar far side) and loitered there for 8 months. Leaving L-2, it flew by the Moon and intercepted the near-Earth asteroid Toutatis, sending images back to Earth, then entered an orbit around the Sun, from where it is still in radio contact. The mission profile of Chang'E-2 documented China's ability to travel, loiter, rendezvous with and intercept any target in cislunar space.

China has demonstrated their capability in anti-satellite (ASAT) warfare, most notoriously with the interception and destruction of a target satellite in low Earth orbit in 2007, creating a hazardous cloud of space debris that threatens the satellites of all nations. A future Chinese ASAT loitering at an L-point could fly to satellites in lower orbits from the Moon, an approach direction not normally monitored. Close contact could neutralize a satellite, either with a robotic

arm to cut a power or communications cable or by deploying a sun shield, putting the solar arrays of our satellite in shade and cutting off their electrical power. We would have no recourse to this type of action and few alternatives short of war. In such a scenario, we would be starting at a decided disadvantage as a result of our lack of commitment to establishing a strong national presence in cislunar space.

America is at a critical juncture in the history of its space program. Congressional leadership is needed to set us back on the correct strategic path. The development of the Moon and cislunar space answers critical national needs. It is an incremental, affordable and useful strategic direction, a sustainable path that creates new capabilities in space faring. A return to the lunar surface allows us to use the enabling asset of the Moon to journey to and explore the planets beyond.

I thank the Committee for its attention, I welcome your comments and thoughts and I am happy to answer any questions that you might have.

PAUL D. SPUDIS is a Senior Staff Scientist at the Lunar and Planetary Institute in Houston, Texas. He received his education at Arizona State University (B.S., 1976; Ph.D., 1982) and at Brown University (Sc.M., 1977). His research focuses on the geological processes of the terrestrial planets and studies of the requirements for sustainable human presence on the Moon. He was Deputy Leader of the Science Team for the NASA-Department of Defense *Clementine* mission to the Moon in 1994, the Principal Investigator of the Mini-SAR imaging radar experiment on India's Chandrayaan-1 mission in 2008-2009, and a team member of the Mini-RF imaging radar on NASA's Lunar Reconnaissance Orbiter mission (2009-present). He was a member of the White House Synthesis Group in 1990-1991, the President's Commission on the Implementation of U. S. Space Exploration Policy in 2004 and was presented with the NASA Distinguished Public Service Medal that same year. He is the recipient of the 2006 Von Karman Lectureship in Astronautics, awarded by the American Institute for Aeronautics and Astronautics, a 2011 Space Pioneer Award from the National Space Society, and the 2014 Eugene M. Shoemaker Distinguished Lunar Scientist Award presented by the NASA Space Science and Exploration Research Virtual Institute. He is the author or co-author of over 100 scientific papers and seven books, including the forthcoming *The Value of the Moon: How to Explore, Live and Prosper in Space Using the Moon's Resources*, to be published in the Spring of 2016 by the Smithsonian Books, Washington DC.

Chairman BABIN. Thank you, Dr. Spudis, for those wise words.

The Chair now recognizes himself for five minutes for questioning.

The first one I'd like to direct to Dr. Spudis. Your testimony highlights the need for a sustainable program rather than one-off stunts, something that you have long espoused. In reference to ARM, A–R–M, your testimony also states that in terms of scientific and operational importance, it is barren of real accomplishment and irrelevant to future human deep space missions. Does ARM fit into the stunt category or is it in the sustainable category?

Dr. SPUDIS. Well, put that way, I believe it falls into the stunt category. I don't think that it necessarily leads on to any permanent creation of capability, and that's what's needed. We need to approach the development of cislunar in a strategic manner so you have small pieces that build upon themselves to a larger whole purpose, and performing the ARM doesn't really gain you anything. It demonstrates that you can do it and that's about it.

Chairman BABIN. And Mr. Young, you testified that a new Administration will be in place in about a year, and that without a plan, it will be very difficult to obtain support and avoid another redo of the context and focus of our U.S. human spaceflight program. Will you please address the challenge of maintaining continuity for NASA's human exploration program, particularly during Administration changes, and what recommendations do you have to address this issue?

Mr. YOUNG. That's quite a good question. My first comment is, it's hard to sell a plan until you have a plan, so that's kind of step one in the process, in my view. My other comment is, it's not just any plan, you know, it's a plan that people both pro and con can recognize it as credible, and I think the ingredients of the plan really exist. One is, as I stated, I think there's a reasonable probability over the next two decades we'll spend $180 billion on human exploration. That's not a bad down payment, and so in my view, you know, that needs to be a critical part of the plan. I do think that'll have to be augmented.

The second thing that I think is really important is to recognize that there is an interest horizon. There's a limit to how long you can hold out the ultimate goal and expect people to be excited about it. I think we could all debate what that is but I'm going to throw out something like going to Mars is two decades. I personally think if it's much beyond two decades, sustainability is pretty difficult. Somebody may say no, it's a decade and a half, but I will throw out two decades. So I think the plan has to recognize that within like a two-decade time period, accomplishments at Mars, if that's our goal, really need to be happening.

I think the other thing that needs to be recognized is, a plan encompasses leadership, and leadership is about making choices, and I think we have to make choices between LEO and the exploration program. I think we have to make choices between the Moon and Mars, you know, as the objectives. So my argument is that if a credible plan can be put together that has a reasonable time frame that makes incredibly efficient use of expected resources, if it's done in a manner that makes hard choices, then I think you have the groundwork or the basic input in order to be able to argue with

the next Administration as to why this should be the sustained activity that should be the focus of the United States human spaced program. The corollary is, without it, I don't think you have a chance.

Chairman BABIN. Thank you, Mr. Young.

For my final question directed to Dr. Spudis, your testimony mentioned that Europe, India, Russia and China have all planned missions to the surface of the Moon in recent years. You also state that as the world beats a path to the Moon, we stand aside. How can we claim leadership in a technological and scientific movement in which we have no participation and seek no ownership?

In 2010, President Obama attempted to cancel deep space exploration and a return to the Moon by flippantly stating "We've been there before." Thankfully, Presidents Eisenhower and Kennedy did not take the same tack and wash their hands of space exploration after we successfully placed a satellite in space, a human in space, a human in orbit, and a human on the Moon surface. Congress rightfully rebuked President Obama's attempt to cancel deep space exploration with the passage of the NASA Authorization Act of 2010, and as we transition to a new Administration, what recommendations do you have for maintaining our leadership in space?

Dr. SPUDIS. Well, I believe that it was a mistake to remove the Moon from the critical path because the Moon basically offers us the opportunity to create capability, and in fact, that's why it was part of the Vision for Space Exploration to begin with. The Moon is reachable, it's close, it's interesting and it's useful. It's close enough so that you can send a vehicle to the Moon any time. It's scientifically interesting in that you can address a lot of problems of wide discipline through lunar science studies and scientific studies to undertake near the Moon. But most importantly, and in fact, this I think is the critical thing to realize about the Moon, is that it is an enabling asset. It's useful. And we've since found in a variety of robotic missions that there is enormous quantities of water in the form of ice at the poles of the Moon. Water's the most useful substance you can have in space. It supports human life. It can be used as rocket propellant. It can be used as radiation shielding. It can be used as a medium for energy storage. So it's an extremely useful substance to have, and it's very heavy, and to launch it out of the Earth's gravity well, which is the deepest gravity well in the inner solar system, basically requires a lot of power, and that's why we need heavy-lift vehicles. By going to the Moon and developing those resources, you can actually create those capabilities by using the local materials that you find there.

Chairman BABIN. Thank you, Dr. Spudis. I appreciate that.

I now recognize the gentleman from Colorado, Mr. Perlmutter.

Mr. PERLMUTTER. Thank you, Mr. Chair, and panel, thank you all for being here.

So we had a bunch of students. Do we have any students left in the audience? Are you guys students? Where do you go to school? And what year are you? And how old are you? Okay. So you're 24. Twenty-four plus 17, you'd be 41 when this is when we should get to Mars, and we had testimony, Dr. Sommerer, I think in December, maybe it was in November, from another panel that said that

from an engineering and an astronomy standpoint, that the star—the planets line up in 2033 to make it feasible for us to land astronauts on the Moon, and so—pardon me—on Mars. And so we put this bumper sticker together that says 2033, and on the bottom "we can do this." And I know, speaking as one but having listened to other members of this Committee that Mars is this aspirational challenge that, you know, sparked something in us, and Mr. Young, you're right. If it's, you know, two centuries from now, we're all long gone, but this young woman, she could be an astronaut and set foot on Mars at that time.

So here are my questions, and I don't think, Dr. Spudis, your testimony is contrary to getting us to Mars. It could be that the way you put the building blocks together, Moon is a key piece of this, and there is no question that it's going to take extreme commitment and extreme understanding to be able to do this well. Our job up here—and this is a quote that we got—I got from astronaut Terry Virts: "Getting to Mars is not a question of rocket science but political science."

So Dr. Sommerer, I'm going to start with you. You said that in your research in the panel's investigation that this was 20 to 40 years, and at least a half a trillion dollars. How did you come to that?

Dr. SOMMERER. First of all, I don't want to get into specious precision about half a trillion. It's on the order of half a trillion.

Mr. PERLMUTTER. Fine.

Dr. SOMMERER. Maybe we'd get by with $180 billion. I don't think so.

Mr. PERLMUTTER. But it's a lot.

Dr. SOMMERER. Yeah, it's a lot of money, and the reason is—by the way, the planets line up every two years basically for Mars, you know, 2033 is a nice round number to have in mind but, you know, it could be two years after that, it could be ten years after that. There's a lot of stuff you need to get people to Mars and bring them back. We need to have a long-term way of keeping them healthy on the way there. They need to spend time on the surface in a potentially hazardous chemical environment. We need to be able to launch them. We need to have prepositioned things that will keep them alive and make it possible to launch them. These are very complicated systems. We can learn a lot in cislunar space. We could have people 3 days away so that if something went wrong with their long-term life support system, we'd have a chance at getting them back, as indeed we did with Apollo 13. But if they're halfway to Mars and something goes wrong because we don't have the experience or we tried to do it a little too fast or a little too cheap, those people are gone.

Mr. PERLMUTTER. But if you had——

Dr. SOMMERER. So let me——

Mr. PERLMUTTER. If we somehow, Democrats, Republicans, Congress and the Administrations—and I figure there're going to be at least five Presidential elections between now and 2033—and I'm happy to give you one of these bumper stickers—and there are going to be 10 Congressional elections between now and then, but if we somehow all came together, said okay, we're going to put a percent of the entire federal budget towards getting us to Mars and

that gets you $200, $300 billion over the course of the next 17 years, can we do this?

Dr. SOMMERER. Yes, but it takes, as Mr. Young has already said, a plan, what we're going to do, what we're not going to do, do the things that are necessary in a logical feed-forward way from the standpoint of technology, don't do everything because——

Mr. PERLMUTTER. I'm just a lawyer, all right? I'm just a lawyer, and my senior partner had this little thing he put on our desks: "Begin. The rest is easy," and then in parentheses, "maybe." Okay? If we were to give you a date that had some legitimate basis in science, 2033, because the planets line up right, can the scientists and the engineers and the technologists build us a program that gets us there by 2033?

Dr. SOMMERER. If you give them a date and the money and help with the discipline, the answer is yes. If any of those three things is missing, the answer is almost certainly no.

Mr. PERLMUTTER. Thank you. I yield back to the Chair.

Chairman BABIN. I'd like to now recognize the gentleman from Oklahoma, Mr. Lucas.

Mr. LUCAS. Thank you, Mr. Chairman, and our friends on the panel, I think we probably have a number of versions of the same question here, and all of you have been before panels before. You understand that's the nature of the body, but as we try to address the issues.

I turn first, Mr. Young, to you. In just two years, the United States will have the ability to return to the Moon with the Space Launch System and Orion for the first time in 40 years, and for the first time ever go deeper into space, providing a historic opportunity for American leadership and exploration. Recently, of course, the NASA Director/Administrator has stated that NASA would be doomed if the next President changes course and deviates from the developments of the Space Launch System and Orion, and if you could one more time to reinforce the point, discuss with us the risks there are in walking away from the investments made in these programs over the last decade.

Mr. YOUNG. First, and I think it's your point, there are no goals that involve human exploration that are significant that are not going to bridge Administrations today, so that's a fact that we're going to have to deal with. And so with a little bit repeating myself but it says that the current Administration needs to approach very seriously the transition to the next Administration in getting forward the rationale as to why sustaining the endeavor across the Administration is an important thing to do. As you're saying what are the downsides if you don't do that, I talked about this $180 billion, and I don't mean to treat that frivolously at all and I also don't mean to say that's everything that's needed, but it's reasonably logical that the activity will be sustained over the next couple of decades at that level. It would be such a shame if what we did was just waste that money and not have a sustainable program really. We have a graveyard today that's fairly extensive that has headstones of human spaceflight programs that consumed a lot of resources and ended up with no basic product, and I don't think we need any more headstones in that cemetery. What we really need is monuments to accomplishments.

Mr. LUCAS. Well put, Mr. Young.

One more question. Part of your testimony indicated that the recent Human Orbiting Mars Workshop organized by the Planetary Society, the Space Policy Institute and the Jet Propulsion Laboratory provides a credible argument that a Mars mission is feasible at constant funding levels. Is there any reason that NASA could not use that as a baseline to plan against? Just expand a little more, sir.

Mr. YOUNG. Yeah. I was not a part of that activity, by the way. I'm familiar with it, and I think that what that what they focused on was a minimum mission. They were just trying to find a minimum credible mission. But I think the real contribution of that endeavor was, they got on the table, on the agenda a plan that most people think have some credibility relative to it to begin the process. Now, the pathway activity that the Congress initiated and was done by the National Academy did a similar thing. As it turns out, the budgeting—I don't know if budgeting's the right way to say it. The cost estimating activity that was done for this minimal mission we referred to was done by the same people with the same process as was done for the pathway activity. So my belief is, there're two options that have a lot of bases behind them. Probably neither one are the option that the country will converge upon but we should put those on the table, and we really should charge the leadership of this country to say look, you know, if we're really serious about humans to Mars, we've got to have a plan, and you know, and here are a couple of versions that says it's not impossible to have a plan. It's not impossible to have a good plan but what we've got to do is to converge on a plan that those who are charged with executing the plan really have, you know, have their own analysis involved in and their own recognition of the importance of a plan.

Mr. LUCAS. Thank you, Mr. Young, and Mr. Chairman, I yield back the balance of my time.

Chairman BABIN. Yes, sir. Thank you.

Mr. Perlmutter, you had actually asked a question of one of my interns back there. That's Alexandra Abney. She's a Texas Aggie, and we're very happy to have her working in our office.

Mr. PERLMUTTER. Maybe she sets foot on Mars.

Chairman BABIN. She might do that. I'm not sure you and I will be around, though.

Mr. PERLMUTTER. Yeah, so carry it on.

Chairman BABIN. Right. Okay. Thank you.

I'd now like to call on the gentleman from Texas, Mr. Veasey.

Mr. VEASEY. Thank you very much, Mr. Chairman, and I wanted to ask the panelists about partnerships and where would international and commercial partnership for human exploration in Mars make the most sense?

Dr. SOMMERER. So Mr. Young has already talked to the very effective partnership that NASA has had with industry and achieving our exploration goals to date and that needs to continue. You can't turn it over to industry. You can't just have it done by NASA in-house centers, I think.

International partnership, the Technical Panel which I led was very explicit that that could be a good thing from the standpoint of sustaining commitment. It's credited as one of the things that

sustained ISS through some particularly dark times. But what it probably doesn't do is save a lot of money. Something like 15 percent of the cost of ISS was borne by our international partners and the rest was paid for by U.S. tax dollars. You would have to have unprecedented levels of international contribution financially to substantially lower the burden on U.S. funding to go anywhere significant, but doing it collectively as a human species as opposed to a set of countries makes a great deal of sense scientifically from the standpoint of soft geopolitics, if you will, and other reasons.

So commercial space entities will always be a part of the NASA program. I think that's necessary. But turning it over to them I don't think makes a lot of sense.

Mr. VEASEY. Are there international partners that we have already identified or that NASA has already identified that we've already begun to have very strong talks with to sort of start laying the foundation for future travel to Mars?

Dr. SOMMERER. I'm not in the Administration so I don't know, okay. I am a member of an international academy of astronautics. There's robust discussion amongst technologists and scientists in that group and in its various conferences, but you know, in terms of actual partners, I presume that we think that the ISS coalition will continue in some form with exploration. Europe has already expressed an interest in a lunar base. There are other significant players out there and some emerging players, and, you know, that's above my pay grade to say whether we should be involved with China or Russia.

Mr. VEASEY. Yes, sir?

Dr. SPUDIS. I'd like to point out that in fact there's already international participation in the Orion SLS system because the Europeans are building service module for Orion, and Orion cannot do anything unless it has a service module. One of the things that could've been looked at that wasn't in 2010 when the Moon—return to the Moon was dropped was getting an international partner to help us build the Altair. The argument of the Augustine Committee was that we couldn't afford to build both the Orion and the Altair—the Altair is the lunar lander part of the Constellation system—at the same time but it was not explored to look at the possibility of having an international participation in the building of the lander. So in actual fact, if Orion and SLS is the future of human spaceflight, we already have international participation.

Mr. VEASEY. Thank you, Mr. Chairman. I appreciate it. I yield back my time.

Chairman BABIN. Yes, sir. Thank you.

Mr. VEASEY. Thank you.

Chairman BABIN. Let's see. I'd now like to recognize the gentleman from Alabama, Mr. Brooks.

Mr. BROOKS. Thank you, Mr. Chairman.

I don't know if you're familiar with the economic news for America that's come out recently, particularly with respect to our deficit and debt, but it's taken a decided turn for the worse. The first-quarter numbers reflect that our revenues went up four percent but our spending went up seven percent according to the Congressional Budget Office, relying on Treasury Department numbers. Our first-quarter deficit was $36 billion worse in this fiscal year

compared to the previous fiscal year. If that were extrapolated out, that would mean that our deficit has gone up $144 billion worse this year than the previous fiscal year although the CBO projects that it will probably be more likely in the $130 something billion range worse. The CBO is also projecting that our total amount of debt is now going to blow though the $30 trillion mark within a decade, and the real question is whether America is going to be able to survive that, whether we will go through a debilitating insolvency and bankruptcy.

So with that as a little bit of an economic background as to our country's finances, my question to you is, how do we avoid a repeat of the Constellation program's demise in 2010 at the hands of the Obama Administration, and a corollary to that is, what lessons did we learn and how can we apply what we learn to the Space Launch System and the Orion programs? The floor is yours.

Mr. YOUNG. I'll take a crack. The budget numbers that you talked about or the economic numbers are sobering, so I don't want to, you know, dismiss them at all. If I would look at myself personally, I would call myself a fiscal conservative so I worry about those kinds of numbers.

I equally worry about what great nations do, and I think great nations do great things, and so I think that relative to the country as a whole, as we go through challenging economic times or challenge of whatever times there may be, I think that we are fortunate that we live in a country that has the ability to also do great things while we're meeting these challenges. So I put myself in that category of advocating working today's problem and planning for great things for the future.

Relative again, and looking a little bit redundant, nothing troubles me more than to spend a reasonable amount of money to come back to maybe my crazy analogy here for another tombstone, and that's why I am personally am passionate about humans to Mars but I'm equally passionate about a good, disciplined plan that is not frivolous, and one of my colleagues commented, a plan that does what is required but also does not do what is not required, or maybe another way to say it, doesn't do just do what is possible. So a disciplined, structured plan that accomplishes what I'm calling what a great nation does a great thing is important. It may be naive but it's my belief that such a plan, well-constructed in a bipartisan, I guess, kind of an effort, I think that kind of a plan should be stable across Administrations, and if we as a country can't do things like that across Administrations, you know, when they're well thought out and well done, then shame on us. I'm an optimist——

Mr. BROOKS. Mr. Young, let me please interrupt. We're running short of time. So any of the other two gentlemen would also like to respond, please feel free to do so.

Dr. SOMMERER. Well, I'd like to reiterate Mr. Young's point, that probably we're going to spend $180 billion on human spaceflight in the country over the coming horizons unless that just stops altogether. Let's spend the money as wisely as we can.

You could make an argument, and some do, and I have from time to time, that maybe we shouldn't have human spaceflight, that we ought to rely entirely on robotic probes, which are much more cost-

effective for the scientific knowledge that's adduced. That's a choice that in really grim financial straits the country might be forced to make. But it doesn't seem to be something that people want to stand up and proudly say let's end the human space endeavor and rely on only robots, although the robot stuff is pretty cool, Mars, Pluto, et cetera.

Dr. SPUDIS. I'll make this very brief, but we're compelled to be present in space for a variety of reasons. Modern civilization critically depends on the assets in cislunar space, so what I've tried to envision is a way to make the human program relevant to those critical needs, and what I've identified is the fact that if you go to the Moon and develop its resources to create a permanent transportation system that can access not only low-Earth orbit but all the points in between Earth and Moon, you've actually created a system that can not only maintain those critical space assets that we use every day but also inherently gives you the ability to go to the planets when you have that.

So I am cognizant of the fact that we're in serious fiscal trouble. We've been in serious fiscal trouble for my entire adult life. But we've continued to spend money on space. We just haven't spent in a focused manner with a clear strategic direction, and I think that's what's needed.

Mr. BROOKS. Thank you, Mr. Chairman. I thank the witnesses.

Chairman BABIN. Thank you, Mr. Brooks.

Mr. Posey is not here so we will go to the gentleman from Oklahoma, Mr. Bridenstine.

Mr. BRIDENSTINE. Thank you, Mr. Chairman.

I'd like to, number one, thank you, Dr. Spudis, for your testimony. You mentioned three things I'd like to hit on. Number one, you talked about three specific missions: cislunar habitats, resource extraction from celestial bodies, and rendezvous, and proximity operations as it relates to doing servicing of satellites, and you were specifically talking about the human components of each of those, and I would like to bring up an issue that I think is important that we need to be talking about here on this Committee, and that is this, that there are commercial entities rising private capital right now that are capable of doing these missions, willing to do these missions, and these private companies. The risk is no longer raising capital, the risk is no longer even technological, although there is some risk there. Their major risk, from what I hear as a member of this Committee, this Subcommittee, the major risk is regulatory. They need certainty. They need to know that when they develop these technologies there's not going to be a government entity out there that says no, you can't launch, or no, you can't do that mission. And these are the challenges that we, I think, need to be addressing and looking at.

When you think about remote sensing, NOAA has the authority to license, you know, remote sensing satellites. When you think about communications, the FCC has the ability to license communication satellites. But those three missions that you specifically mentioned, these are non-traditional kind of missions that we haven't been doing commercially yet, and yet right now we're raising capital—I say "we"—private companies are raising capital to do these missions, and we need some kind of regulatory assurance

that when they are ready, that there is nobody that's going to put the halt on their efforts. So thank you for bringing up those, and of course, I think your vision for cislunar space is critically important.

I know a number of other people have touched on this but I want to be really clear, and I know, Mr. Young, you're not here representing the NASA Advisory Council. I know you're a member of it but you're here, you know, operating independently. But the NASA Advisory Committee warned that NASA runs the risk of squandering precious national resources if they move forward with the Asteroid Redirect Mission. Later, the NASA Advisory Council unanimously adopted a finding that it thinks NASA should change the Asteroid Redirect Mission into a mission that would go all the way to Mars and thus be more closely aligned with the goal of sending humans there.

Mr. Young, two years ago you went as far as to say that the ARM proposal "dumbed down NASA."

Mr. Spudis, your testimony states that "ARM offers few scientific and scant operational benefits" and that "in terms of scientific and operational importance, it is barren of real accomplishments and irrelevant to the future human deep space missions."

Dr. Sommerer, your testimony highlights that the NRC panel that you participated in found that NASA's current plans which include ARM have "serious deficiencies with regard to the significance of intermediate destinations, logical feed forward, dead-end systems and exceedingly high development risk."

That is not good testimony regarding the Asteroid Redirect Mission from any one of you. My question is really simple. Why, if there's this much consensus, why is the Administration still trying to force this mission on NASA, the scientific community and the American public? And I'd like you guys to speculate on that if you would. I have 1 minute left, and I'll just leave it to each of you. I'll start with you, Mr. Young, or you guys can decide.

Dr. SOMMERER. Fairly early in President Obama's Administration, he said we're not going to the Moon, we're going to an asteroid because we've been to the Moon. We did not actually have the capability to go to the asteroid for the foreseeable future for reasons that we've discussed. I think it is likely that that's an embarrassing position to be in, although I don't know what it's like to be President, and there were some people who came up with an idea that sort of got astronauts into the business of playing patty-cake with something that came from an asteroid, at least, and that seemed very attractive. But I agree with all of the statements that I think it's a mission which has no real purpose, especially in the context of deep space exploration.

Mr. BRIDENSTINE. Mr. Young, did you want to add to that?

Mr. YOUNG. No, I think I basically agree with the comment. I don't really know the answer to your question obviously. The reason for my comments and the other comments is that again I feel so strongly that we need to be doing those things that are critical to a successful human to Mars program and the mission, the Asteroid Retrieval Mission, is far below threshold as to a mission that contributes to that endeavor, in my view, and again to come back to relevant to that, one of the things that's argued is, well, out of

that mission we got some technology and the technology is on the solar electric propulsion tug, and I think that's true, and the SES technology is needed, so do the technology. Don't encumber it with all of the other activities that's there, and I think that's why the NAC said look, a terrific thing would be taking SES flight to Mars, bringing it back and demonstrate the technology in a manner that it'll ultimately use relative to Mars.

Mr. BRIDENSTINE. And I'm out of time. Mr. Chairman, in closing I would just like to say that going back to my original statement, as these private companies are raising capital and they're retiring technological risk and they're ready to launch, we need to make sure this Committee is 100 percent committed to enabling and allowing them to do what they're supposed to be doing, which is advancing the human condition with commercial and private-sector capabilities.

So thank you so much.

Chairman BABIN. Yes, sir. Thank you, Mr. Bridenstine.

Mr. Posey, the gentleman from Florida, is back in here and so I'd call on him for a line of questioning.

Mr. POSEY. Thank you very much, Mr. Chairman.

Dr. Spudis, in your testimony you stated that the United States abandoned the strategic goals for space set by Vision for Space Exploration in 2010 and eliminated the objective of a lunar return. The elimination of lunar return has left a vacuum in the National Space Exploration Policy that has yet to be filled. Should the United States return to the Moon in cislunar space and, if so, how does that fit, in your opinion, within a longer-term human exploration strategy?

Dr. SPUDIS. Well, yes, sir, I do believe that, that the Moon played a critical role in the original Vision for Space Exploration in that it was a key enabler. It both enabled you to create the technology you needed to go deeper into space beyond low-Earth orbit and it also offered the ability to create all new capabilities such as the provision of consumables and propellant from lunar materials. So for this reason, I've advocated lunar return for a long time. The more we learn about it, the more promising it appears as a target, and you have to be able to build a system in an incremental manner using small steps so that you don't necessarily have a big wedge of money that you need to get started but at the same time you create long-term capability.

So in my opinion, focusing on the development of cislunar space and specifically development of the resources of the Moon actually can create new capabilities that we currently don't have, and that includes the capability to go to the planets.

Mr. POSEY. Virtually—and I may have forgotten who did it but every witness we've ever had come before this Committee has said we need to have a lunar basis as part of the steppingstone. The only one we haven't got that from is NASA.

Dr. Spudis and Dr. Sommerer, can you discuss what are the most important elements of the planned cislunar habitat that feed into the longer-term plan for the journey to Mars? What key technology development and scientific research can be done that will feed the forward to a human mission to the Martian system?

Dr. SOMMERER. One of the salient features of a mission to the Martian system is how long it takes, given our current propulsion capability and those we foresee could take years, at least a year. We've learned a great deal about environmental control and life support systems as part of the ISS. However, and I have this on authority from the engineers who are responsible for that, it's kind of a kluge. There's a lot of things that have been put together over time. They aren't totally compatible. You would, I would think, if you're an astronaut on your way to Mars, want to believe that that environmental control and life support system was going to be very reliable, not require constant maintenance, and was going to get you there safely. That's one of the things that you could do in cislunar space. You could develop that capability in cislunar space where you're only three days away from help if something does go wrong. That would be a very, very important contributor to Mars.

The other thing that you can't do on the ISS is deal with galactic cosmos rays because it's such low altitude and deep in the Earth's magnetic field. We need to have a lot more experience with what radiation does to people on long-duration missions. That's something also that can happen in cislunar space where people are pretty close to help if things are going badly. Those are two things that I think are absolutely critical.

Mr. POSEY. Yeah, I'm a son of Apollo when they did all that without computers. They did it with slide rules. You know, as President Kennedy said, great nations do things because they're difficult, because they're hard, actually, he said, not because they're easy, and certainly this falls in that ballpark.

Dr. Spudis, it's my understanding that commercial lunar mission backed by private-sector investors could be launched to the Moon as early as next year. As an advocate of lunar resource development, do you see value in commercial robotic missions and do you think NASA could benefit from including payloads on those missions?

Dr. SPUDIS. Yes, I do, and I should preface this by saying I'm involved in one of those commercial companies. I advise Moon Express Incorporated on possible payloads. But in actual fact, there's a lot that you could accomplish with small robotic missions to help prepare the way for both human return and the development of lunar resources. For example, if you were able to fly a set of instruments that could measure surface hydrogen on a small lander and land it near the lunar poles, that is a key critical piece of strategic information that we don't have. It would also allow us to calibrate the remote sensing data that we have. I think it would be a very good investment of NASA funds to help provide instruments like that to any of these commercial missions for the simple reason that it's a cheap and inexpensive way to get very valuable long-term strategic information.

Mr. POSEY. Okay. And for you and Mr. Young, as seen with the successes of Commercial Cargo program and the progress being made with the Commercial Crew program, can you discuss in more detail how NASA can leverage public-private partnerships as human exploration program extends beyond the low-Earth orbit?

Mr. YOUNG. That's a broad question. As I said earlier, industry is a critical component of the exploration program in partnership

with NASA. The commercial activity—I'm going to use Commercial Cargo as an example—in that particular circumstance, NASA or the country has turned a lot of the responsibility over to the commercial supplier, and I think in that instance, it was a good thing to do, and it was a good decision.

I think we've got to be careful when we talk about exploration as to how we use the term "commercial," and what I really mean by that is, I think it's going to take the best of NASA, the government and industry to do a human to Mars mission, and we should not do commercial experiments as a part of that endeavor. So I don't know whether I've specifically answered your question or not but I think there's a spectrum where the real term commercial makes an awful lot of sense and there are other activities where the nation has to provide the leadership form government with industry being an implementing partner to make things happen, so that's what I was trying to say.

If I could—I know I'm cheating, but if I could make one comment on cislunar space that you talked about. I think there are and I agree with the Kennedy statement, which I think was good, but I think there are things that can and should be done in cislunar space that are necessary in order to have a human to surface of Mars mission with an acceptable probability of success. However, my caution would be, we don't need another space station in cislunar space that is basically going to be carrying on an R&D program there, and I think that was your implication also. So I think that again the plan we keep talking about will allow us to make the judgment as to in cislunar space, what is required, and we need to separate that from what we can do there because what we can do is probably—not necessarily what needs to be done. I think cislunar space needs to be planned very well or it itself can become an enormous user of this resource that we're talking about.

Mr. POSEY. Thank you, Mr. Chairman.

Chairman BABIN. Yes, sir. Great line of questioning there.

Now I'd like to recognize the gentleman from California, Mr. Rohrabacher.

Mr. ROHRABACHER. Thank you very much, Mr. Chairman, and thank you for holding this hearing. I'd like to identify myself with the comments of Congressmen Brooks and Bridenstine earlier. They made some very good points, and I'd like to also identify with our witness, Mr. Spudis. Is that how you pronounce it? Okay, Mr. Spudis, who is admonishing us to do things incrementally because it's affordable and getting something accomplished as compared to laying down a 20-year program of gigantic spending that will suck the money away from all the other projects that—NASA comes to mind in the next 20 years. In the next 20 years, I'm sure we will have lots of great ideas that may be more important than spending money on getting a man to Mars and planting a flag and coming back. In fact, if the Mars mission is to be successful, it appears to me that we need,if we were to say our goal is to have an American on Mars, we need to ask for volunteers and say you're not coming back, that's the only way that would be affordable, and that's just a thought.

In terms of the greatness challenge, I agree with you. America needs to do great things, and we are doing great things, but inspire

young people—we now have reusable rocket system being developed, and that came from the private sector, and we have, you know, Virgin Galactic about ready to make suborbital space a major part of Americans and western civilization because it's going to spread us all over the world in a matter of minutes. These are great things that these young people are going to be able to participate in that didn't exist before. Blue Horizon, SpaceX, Virgin Galactic, they're doing great and historic things.

Let me just note that if we do decide, and it looks like go to Mars, I've heard this for 20 years, it looks like that's what people are forcing into this mode of spending. Ten years down the road, ten years down the road, if we have committed ourselves to so many billion dollars every year that we're spending and we end up spending $20 billion, $30 billion down the road and let's say at that point a meteorite, instead of skimming Russia like it did in 2013, a meteorite would hit a city and kill hundreds of thousands of people, can I tell you what that would do the priority of space spending for this body? They would cut everything off because then the public would demand that we were spending our money on global defense rather than on planting the flag on Mars, and all of that money that we'd spent then would've been wasted. What I just described is not a scenario that will never happen. It may never happen but it could well happen. There's nobody in this room who believes that might not happen in the next 20 years.

So let's make sure that we do things incrementally so when we are spending at least if we do have to change spending priorities in the future, all of that money won't be wasted, won't be right down the toilet. We can't afford to do that. As Mr. Brooks pointed out, we can't afford to waste billions of dollars. We just can't afford that. It will bring us down as a country rather than uplift our country, which is what the space program is supposed to do.

So I would suggest that maybe we need to calibrate our plans. We have global defense, which I just mentioned, is really an important thing. Clearing space debris—pretty soon we're not going to be able to use space unless we actually initiate a program that's going to clear the space debris that will—again, when we're talking about our young people, our young people, they're used to now living in a world where we have GPS and we have telephones and we have all sorts of utilizations of space, and unless we start clearing that debris, there's going to be no more ideas about utilizing space because there won't be any space up there to do this. It'll be filled with debris.

So we have these challenges, and I would just hope that as we're discussing manned missions to Mars, that we keep in mind that if we end up defunding all these other programs, it'll bring us down. It'll bring the American space program down.

So with that said, let me ask about the Moon. I guess I'm already over. I'm sorry. By the way, Mr. Chairman, I was the Chairman here of this Subcommittee years ago, and frankly, we had to force NASA to go around the Moon by the poles in order to find out if there was going to be water or not. We had to basically force NASA to do that. They did not want to change the pattern of just going around parallel.

Give us—and you already mentioned this in passing. Give us an example—again, if we have water on the Moon and we've expanded—now we know there's considerable water, that will permit manned presence on the Moon and will then also permit us to further manned use of space beyond the Moon. Is that correct?

Dr. SPUDIS. Yes, sir. Effectively, the Moon has two resources to offer at the poles. One is the water, which is in the form of deposits of ice that have been stable for billions of years, and apparently it's present in massive quantities. If the estimates from our remote sensing are correct, there are at least hundreds of millions of tons. I personally think there are over billions of tons.

The second thing you have that's critical are zones on the Moon near the poles which are in near permanent sunlight, which allows you to essential stay on a sustainable basis on the Moon. Now, water is useful both for sustaining human life—you can drink it, you can use it for sanitation, you can protect yourself from radiation—but more importantly, it's the most powerful chemical rocket propellant we know of. If you split water into its component atoms and then freeze that into a liquid, you've got liquid oxygen and liquid hydrogen, which is basically what the space shuttle main engine uses. There's enough ice at the poles of the Moon to launch the equivalent of a space shuttle every day for over 2,000 years. So that's a lot of water. You're not going to run out of it soon. And if you're able to access it and process it and store it and send it into space, you've actually created a fueling depot that will allow you to go Mars on a sustainable basis.

Mr. ROHRABACHER. What would it cost—now, we're talking about—we just mentioned the costs of going to Mars. What's the cost of what you're talking about?

Dr. SPUDIS. It depends on how you approach it, and a lot of people have published ideas on this. I have published a paper on it. There was another paper this past summer. But I certainly think it's less than $100 billion. The key is to use robotic assets to get started, and then use people as they become necessary. So you can do this on the Moon. You can't do it on asteroids and you can't do it on Mars because the Moon is close. So you're able to remotely control robots via teleoperation from the Earth, and you can't do that on the more distant targets.

Mr. ROHRABACHER. Well, I just note, Mr. Chairman, when I talk about the potential of our space commercial sector and space refueling is also something they could do more not from Mars, and again, a private company might want to put up a space refueling station, and that would enable us perhaps to bring down the cost for space exploration and also for Moon missions.

And one last thought, and that is, I really think Elon Musk is going to be on Mars before NASA gets there, and it's just a thought. Thank you.

Chairman BABIN. Thank you, Mr. Rohrabacher.

I'd like to recognize the gentleman from California, Mr. Knight.

Mr. KNIGHT. Thank you, Mr. Chair.

You know, there's been a good discussion here today. I think that a lot of this does revolve around money. I think much of it revolves around technology. I think that Mr. Perlmutter might want to change that bumper sticker, and just the first number. You don't

have to change the second number but the first number in the years there. It's not going to be 2033. We are a ways away from going to Mars and getting back. We can go to Mars but getting back is going to be a problem.

I think that one of the discussions about Apollo 13, when you're 100,000 miles away, it's a lot different than when you're 25 million miles away. There is no help at 25 million miles. So that is a distinct problem that Americans probably will not take for their astronauts to be in that kind of peril anytime soon.

The second thing is money. If we're going to spend $12 billion on this over the next 15 years or 17 years to get us there, that will be an issue. Right now, NASA only spends about three percent of their budget on aeronautics, and I have complained about that and I'll complain about that as long as I'm in Congress. I think that that is criminal that we spend three percent of our budget on aeronautics when a lot of the products that comes out of NASA is for us right here, either in general aviation or in commercial aviation, and we still only spend 3 percent.

We have been working on scramjet technology for 50 years. We are still working on that. We are still a ways away from that, and I think that that technology is part of a big problem.

But I have a question, and that is on the lines of the experiments we've done in the Space Station, and one of the experiments that's happening right now with a twin on the ground and a twin at the Space Station for a year. Do any of you believe that at this point we can say that safely a man can travel or a woman can travel to Mars and be returned to Mars in maybe a two-and-a-half-year mission, and with what we know today, do you believe that that is doable, feasible? Not doable, but yes, we will get something back, that that person will come back.

Dr. SOMMERER. I think it poses a significant risk based on what we know. NASA actually has a pretty good human research program but given the resources that they're dealing with, there are significant uncertainties about what the microgravity and the radiation impact to say nothing of the chemical hazards that Mars might do to the health of astronauts.

Mr. KNIGHT. My second question, I think you hit on it earlier, is the propulsion. Our propulsion hasn't changed in many, many years from basically the beginning of rockets. It's going to take us about a year to get to Mars today. Do you see over the next 15 or 20 years some sort of propulsion system that is going to speed that up dramatically so that we can get to Mars in maybe a less than six-month period?

Dr. SOMMERER. Certainly, I don't see it happening if we don't work on it.

Mr. KNIGHT. And I would make that statement to everything. If we spend the money and we work on it, I believe that the American ingenuity can do this. I believe that we can do this in that time period. I don't think that there is a push to do it, and I don't think there's a push to do it consistently. And Mr. Rohrabacher talked about an awful lot of programs that—and Mr. Young talked about the headstones in the cemetery. I believe that, but I also believe that you get things from that.

There was a program in the late 1950s and early 1960s called the X–20 Dinosaur. I think that that was the first space shuttle that we would have ever built and it would have been very successful. We abandoned that program for lack of a mission and for funding, and we wanted to send a man to the Moon.

I think that we learned an awful lot from the X–20 Dinosaur, and I think if Jeff Greeson was here today, he would say we learned an awful lot because he's building something that is very similar to the X–20 Dinosaur.

So just because a program was canceled or just because a program never left the launching pad doesn't mean we didn't learn something from it, doesn't mean that that money might not have been well spent. But I will agree with Mr. Rohrabacher. If we don't use the program and we spend hundreds of billions or tens of billions, the taxpayers do feel at a loss.

So I think that NASA can do anything that they put their mind to and anything that we can fund. Thank you, Mr. Chair.

Chairman BABIN. Yes, sir. Thank you, Mr. Knight.

I think this has been an excellent exchange of ideas from you expert witnesses. We really appreciate this, and—because there's a great deal of question marks out there about what we're going to do and the missions we're going to have, and the old saying, do we have guns or butter or guns and butter, and obviously today all three of you, if I'm reading you right, say it's got to be either guns or butter in this situation about whether we go to Mars or back to the Moon. And we have our work cut out for us.

And I agree that whatever NASA puts their mind to, we can do, but we do have the parameters of an almost $20 trillion national debt that we have at this point in time, but I think with what we gain from our space program, it is in great—as you said a while ago, Mr. Young, great nations do great things, so I think we have our marching orders. We just have to get organized on this.

So I just want to say thank you to all three of you, and thank you to the audience out there, and thank you for this line of questioning. And so I adjourn the hearing.

[Whereupon, at 11:50 a.m., the Subcommittee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Mr. Tom Young

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

"Charting a Course: Expert Perspectives on NASA's Human Exploration Proposals"

Mr. Tom Young, Former Director, Goddard Space Flight Center, NASA; Former President and Chief Operating Officer, Martin Marietta Corporation

Questions submitted by Rep. Brian Babin, Chairman, Subcommittee on Space

1. I believe solar electric propulsion (SEP) is an important element of a humans to the surface of Mars Program and should be further developed. I do not believe the Asteroid Retrieval and Redirect Mission is necessary or important to the human Mars exploration program and is actually a distraction. A more constructive application of SEP would be a demonstration as a part of a robotic mission to Mars or one of the moons of Mars.

2. I believe the Asteroid Retrieval Mission (ARM) contribution to landing humans on Mars is a net negative as discussed in the answer to Question 1. Activities in cislunar space will be important in preparation for the Mars exploration program. The humans to Mars effort will be most demanding of our intellectual and financial capabilities. Great care must be exercised to assure only those activities that are required for the Mars endeavor are included. Those activities that can be performed, such as ARM, but are not required for the Mars mission should not be part of the plan.

3. While the exploration of the moon and Mars are both challenging and worthy goals for the U. S. human spaceflight program, only one is affordable. I believe Mars is the most compelling goal as cited in the NASA Authorization Act of 2015 passed by the House of Representatives. Therefore, I believe only those activities required for the Mars endeavor should be pursued.

4. I do not believe a Low Earth Orbit (LEO) and a Mars (or moon) exploration program are affordable. As a result, we should accomplish the necessary human research on the ISS as soon as possible and redirect residual resources to the exploration program. Hopefully, this can be accomplished well before 2024. NASA should encourage and support, as the Aeronautics program does for commercial aviation, commercialization of LEO; however, the private sector should be responsible for making it a reality.

5. My answer to Question 4 is a partial response to this question. I do not believe the government has a further obligation beyond the current ISS activity, including commercial cargo and crew. The private sector must provide the leadership for the further commercial development of LEO.

6. SLS and Orion are important elements of the U. S. human spaceflight program. I believe they will be viewed positively in the context of a Mars (or moon) human exploration program. They are also important in maintaining NASA and industry capabilities.

7. I believe the most significant benefit of a U. S. human spaceflight program is "Great Nations Do Great Things". This is also the ultimate "soft power" impact. Clearly there will be primary benefits to technology that will flow from the program but it is difficult to forecast specifics.

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"Charting a Course: Expert Perspectives on NASA's Human Exploration Proposals"

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Questions submitted by Rep. Jim Bridenstine

1. To have a habitat module ready for deployment by 2018 will be a challenge. I do not see a business case that would justify a significant investment by a private sector partner. Hopefully, I am wrong.

2. We must decide if the U. S. human spaceflight program is to continue to focus on LEO after ISS and commercial crew or move beyond LEO. Clearly we cannot do both. My belief is that NASA should focus on human exploration beyond LEO and the private sector should take the leadership role for the future of LEO with modest NASA support. One note of caution, I believe the success of commercial crew will require the application of the full capability of NASA and the extraordinary implementation capability of industry.

3. We have a lot of experience that says that the probability of success of launch vehicles increases as the launch rate increases. My judgment is that launching once every three years is unacceptable for mission success and costs reasons. Launching once a year is a concern that requires more study. A detailed study by an organization such as the Aerospace Corporation should consider the degree of risk associated with a once per year launch rate and special actions that can improve the probability of success.

4. There are many science, planetary and national security missions that could fly on SLS. Decisions will be made based on reliability, cost and issues of the government competing with the private sector. Each of the issues needs to be addressed in the operations planning for SLS.

5. Yes! I do not see how it is possible to execute a credible human exploration program without a reasonably detailed plan for the total program.

6. I believe commercial cargo maybe advantageous as a part of the cislunar activity. I do not see a NASA role for commercial crew after ISS. Hopefully, the private sector will need commercial crew as it develops the commercialization of LEO.

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

"Charting a Course: Expert Perspectives on NASA's Human Exploration Proposals"

Mr. Tom Young, Former Director, Goddard Space Flight Center, NASA; Former President and Chief Operating Officer, Martin Marietta Corporation

Questions submitted by Rep. Donna Edward, Ranking Member, Subcommittee on Space

1. A plan with sufficient detail is needed today. The plan should cover the total program from today to humans on the surface of Mars. The detail should be adequate for all participants to know the plan, adequate to make technology development decisions, to identify intermediate destinations etc. and adequate to generate support. A plan should always have the flexibility to make changes when required by new information. This is the process we have followed in the implementation of space projects for decades. It is hard to understand why we don't need a comparable plan for the most challenging endeavor we have ever pursued.

2. The JPL Study suggests that a minimal human to Mars mission is feasible if the current human spaceflight budget is concentrated on this objective. While some may believe that more than the minimal mission will be required, the study suggests that two decades of 8-9B$ per year for a total of 160-180 B$ is a lot of money and if properly focused much can be accomplished. My current concern is that the current approach will spend the budgeted funds with far less being accomplished than that which is suggested to be possible by the JPL Study.

3. Exploring Mars is hard as has been demonstrated by the robotic program and studies in preparation for a human mission. We know a lot about the technology challenges; however, the technology requirements are not well understood or defined. To the best of my knowledge, NASA does not have an adequate plan. I don't see how Congress or anyone can measure progress without a plan.

4. Radiation is certainly an issue and a challenge. The issue needs to be treated as a project within the Mars project. This is the way we typically handle difficult challenges within a project. My understanding is NASA has made considerable progress on the radiation issue.

5. I agree. I do not believe it is responsible to have a humans to the surface of Mars mission without first having a robotic sample return mission. It is troubling that the future Mars robotic program does not appear to include a sample return mission, given its importance for a human exploration mission and the priority established by the Planetary Decadal Study.

6. I believe planetary protection is an important priority consideration. My limited observation of the current NASA activity is that it is out of control. Leadership is critical to assure that risk

is responsibly assessed and balanced actions are implemented. We know how to responsibly manage risk. We need to apply our risk management experience and expertise to this important area.

Responses by Dr. John C. Sommerer

Questions for the record regarding testimony of John C. Sommerer, February 3, 2016
House Committee on Science, Space, and Technology, Subcommittee on Space

Comment: Many of the questions raised by the Committee go beyond the scope of the NAS report *Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration.* The following answers should be considered the opinions of the witness, unless a specific reference is made to the NAS Committee on Human Spaceflight, or the Technical Panel supporting it.

Questions submitted by Chairman Babin

1. The Administration contends that the ARM mission is part of the journey to Mars and will assist the development of future human Mars missions. What specific mission elements of the ARM mission are necessary for a human Mars mission?
   Sommerer: The ARM mission would use an SLS and Orion capsule for astronauts to interact with the asteroid fragment. As articulated by NASA, a twice-upgraded version of SLS, and an advanced version of Orion would be used for a human Mars mission. The solar electric propulsion system proposed for the asteroid redirect part of ARM is articulated by NASA as usable for prepositioning cargo or other systems at Mars for a human Mars mission; while this may be true, it requires the development of an additional propulsion system beyond what is required for a human Mars mission.
   a. What about these elements requires an asteroid in distant retrograde lunar orbit to be tested? Is it not possible to accomplish those goals without the asteroid?
      Sommerer: Nothing, and yes, respectively.
   b. What specific scientific mission tasks or goals require the presence of human astronauts on an asteroid in the current mission architecture?
      Sommerer: None, if by current mission architecture, the Chair is referring to the DRA 5 design reference mission (for humans to Mars) examined by the NAS Committee on Human Spaceflight. It is conceivable that astronauts interacting with a substantial asteroid (not the fragment currently envisioned for ARM) could facilitate human interactions with the Martian satellites Phobos and Deimos, in a mission placing humans in the vicinity of Mars, as articulated by the Administration. However, the NAS technical panel considered that placing humans on Martian moons may not be feasible, given the galactic cosmic ray hazard on an extended mission. Finally, if that hazard is currently overestimated, or can be mitigated, robotic exploration of the Martian moons would be necessary anyway, as they are not considered to be asteroidal in origin; thus the robotic capture of an asteroid fragment for ARM would be superfluous.

2. Clearly NASA has adopted the "horizon goal" .... What benefits will NASA receive from developing a cis-lunar habitat?
   Sommerer: A cis-lunar habitat would allow demonstration of all necessary features of a deep-space habitat, including any radiation mitigation technologies that may be possible (almost certainly limited to Solar Particle Events, and not relating to Galactic Cosmic Rays), that would be needed for a human mission to Mars. Note that because of the Earth's magnetic field, a LEO habitat (or ISS module or formation flier) cannot be used to test the latter highly desirable technologies. A cis-lunar habitat would offer the advantage of proximity to Earth or LEO, potentially allowing for rescue of a crew which, due to system failure, or other mishap, became endangered.

a. What benefits would NASA get from doing a habitat vs. asteroid retrieval? What type of crossover is there from the development of this habitat and other possible intermediate destinations to Mars?
Sommerer: Any deep space human exploration requires a habitat. The availability of a reliable habitat will be necessary for any human mission with a duration longer than the endurance of the Orion capsule, which currently is no longer than a month. Beyond the life support issues associated with Orion, habitats offer significant potential for reducing psycho-social issues for astronauts, including the option of having larger crews involved in deep space missions. As noted during the hearing, an asteroid adds nothing to the development of pathways for human space exploration beyond LEO. However, note that the NAS Committee determined that the entire scope of human exploration for the foreseeable future would be the Moon, near-Earth asteroids, and the Mars system.

b. If NASA were to develop a deep space habitat, should it be done as a full and open competition, given the fact that commercial providers seem to be fairly mature? Bigelow Aerospace .... What is the best way to leverage private sector investments without the government crowding out their innovation?
Sommerer: One of the primary lessons learned from the ISS experience is that multiple independent systems developed by multiple providers (i.e. the international partners and their supporting contractors) can vastly increase the maintenance burden and logistics chain needed to support a project. A particularly salient example of this is the consumables (e.g. CO_2 scrubbers) associated with Environmental Control and Life Support Systems (ECLSS), which are different in various parts of the ISS. To reduce this operational burden, it is essential that NASA establish and enforce open-standard interfaces for ECLSS and other systems. The benefits of open competition can easily be swamped by the need to support separate logistical chains with sometimes implicitly embedded proprietary differences. Similarly, the opportunities for "technology refresh" can be limited by implicit incumbency of early contributors. This lesson has been learned painfully by the DoD in the case of the littoral combat ship (LCS), where two, different, "open" architectures are now present, each separately developed by the two different Lead System Integrators and their respective teams. Given the decades that meaningful human exploration will span, it is essential that there are opportunities for multiple contractors to contribute seamlessly, despite budget fluctuations, programs slipping to the right, or contractor bankruptcy. Providing this pathway for ongoing development is one of the most important roles that NASA can provide.

3. NASA will need...
   a. Are there benefits to landing on the Moon before going to Mars?
   Sommerer: Yes. A lunar program will, as outlined above, allow development of necessary technology such as ECLSS and deep-space habitats. Other possible benefits might involve surface habitats, surface power systems, surface transportation systems, and human health studies regarding the extent, if any, to which reduced gravity on the Moon mitigates the problems associated with exposure to zero g (lunar gravity is approximately 0.16 g, whereas Martian gravity is approximately 0.32 g). However, the technology required to land heavy systems on the airless Moon, and that required to land on Mars, with it's tenuous but non-negligible atmosphere, are necessarily quite different. Thus landing on the Moon will not directly translate into readiness to land on Mars.
   b. What would the programmatic and monetary tradeoffs be if NASA attempted to build up a larger, more permanent presence?

Sommerer: This is a very complicated question. A lunar program, particularly one that involved substantial, sustained human presence on or under the lunar surface, would, in a constant budget environment, substantially slow progress toward humans on Mars, just as sustainment of ISS is slowing progress beyond LEO. However, given the extreme technical difficulty, programmatic complexity, and probable length and cost of sending humans to Mars, perhaps a human presence on the Moon in the shorter term would be preferable to continued confinement to LEO.

c. Could NASA maintain a human presence on the Moon and attempt to send humans to Mars under a realistic future budget scenario? Would this depend on the scale of a Mars mission (i.e. flyby versus landing)?
Sommerer: If by "realistic," the Chair means "similar to today's expenditures," I consider neither a human presence on the Moon nor humans in the vicinity of Mars to be likely within the next 50 years. Although the scope of required technology is significantly reduced for a human flyby (or orbital) mission to Mars, relative to humans landing on Mars, it is still daunting, and probably increases the risks to a human crew. Further, the prospect of a human flyby mission to Mars begins to seem more like a "stunt" than genuine exploration: the closest approach to Mars would be brief, and would occur on the night side of the planet, thus providing precious little that cannot be achieved robotically, other than the ability to say "we did it." Finally, orbital missions to Mars (or missions to Mars' moons) where astronauts teleoperate robots on the surface, may not be feasible due to the radiation risks posed to the human crews in the deep space environment.

4. How do you think the upcoming SLS and Orion missions will resonate with the American people, and people around the world? What are the potential "soft power" and secondary impacts of these high profile missions?
Sommerer: I am almost certainly not the right person to predict this. While there is very genuine interest in the robotic exploration of space (as evidenced by the recent Pluto flyby, the continuing interest in the Cassini, Curiosity and DAWN missions), it seems that the pace of missions involving SLS (with a very low launch rate metered by the extremely high cost of the rocket), and the relatively modest accomplishment of each of the two planned EM missions, relative to the unrealistic but frequently publicized claims that "we can be on Mars in 10 [or twenty, pick your number] years," I think there is likely to be a public letdown. With regard to "soft power" it will certainly indicate that the US didn't "give up" and indeed has the capability to still build high-performance rockets. However one has to measure that (in terms of cost) against other possibilities for NASA to "softly" project US power and influence through, say, robotic missions with the ability to address the global human condition. Examples include environmental monitoring (including climate change), planetary defense against "small body" impact, and heliophysics/space weather.

5. NASA has performed numerous launch vehicle architecture.... What opportunities would SLS' capabilities open up with our international partners on human and science missions? Would this new launch capability provide the US with a new tool for international cooperation on various projects?
Sommerer: The most salient feature of SLS is its size (and its associated cost). Just as NASA, its international partners, and the USAF retreated from the use of the Shuttle as a "routine" transportation system to space because of the huge costs (and decreased reliability and availability) of a human-rated system relative to more modest, expendable launchers, it is hard to see that SLS will find extensive use outside the human exploration

program. Although JPL has expectations that the planned Europa mission will launch on SLS, one wonders how often things like that will happen (launching a $2B payload on a $4B rocket). Similarly, the USAF is currently focusing on the "disaggregation" of our large, and expensive, national security systems in space, to increase the overall survivability of our assets in an age of asymmetric challenges to the US. Will the USAF want to foot the bill for SLS, when it is launching smaller systems? I think not. With regard to international cooperation, it is clear that Europe would prefer a "Moon first" approach to human exploration. SLS could indeed facilitate such an approach. But again, if one looks at the European cumulative investment in space, it is unlikely that they will pay a significant fraction of the price (as indeed, all the international partners, besides the US, contributed on the order of 15% of the cost of ISS). Indeed, if the current pattern of NASA reneging on, or postponing commitments to partner with ESA on scientific space missions in order to pay the development bills for our human systems continues, SLS is likely to actually damage our cooperation with traditional space partners. The other countries with the capability to significantly defray the cost of deep space exploration (Russia and China) are the countries that we are least likely to invite to partner with us in the use of SLS, for any purpose.

Questions submitted by Rep. Bridenstine

1. The FY2016 Omnibus Appropriations bill directed NASA to have a habitat ready for deployment by 2018. Will NASA need to partner with the private sector in order to make this date?
   Sommerer: Almost certainly. One of the most important considerations here, however, is the realism of the bill's target date, in the context of what is meant by "habitat." If "habitat" is just a structure that would accommodate astronauts and ancillary equipment to be specified at a later date, then the private sector is capable of supporting NASA in meeting the specification of the Appropriations bill. However, if "habitat" includes highly reliable Environmental Control and Life Support Systems (ECLSS) that would be needed for long duration missions of humans in deep space (to say nothing of radiation hazard mitigation), it is unlikely that NASA or the private sector would be able to develop a system on the bill's timetable. A key question for the Congress is whether setting such a deadline will materially advance human exploration goals, or will it result in a dead-end system that will need replacement "from scratch," on a longer time table?

2. Congress just extended ....
   a. Do you think establishing a commercial habitat pilot program in order to test the viability of commercial habitats as an eventual replacement of the ISS would be a prudent step for NASA to take?
      Sommerer: Yes. But given the extremely long time over which human space exploration is going to make material progress, it is extremely important to allow for "technology refresh" and interoperability of systems provided by different partners and contractors. So, while pilot programs can "test the water," it is important not to establish "incumbency" for the initial contractors, particularly in a budgetary environment where human spaceflight expenditures might be volatile. A pilot program should be used to investigate viability, with a finite time horizon, and transition to a program of record. The participants in the pilot should derive their primary benefit from flight and development experience, and not from becoming a de facto monopoly. Finally, note that if a primary goal is to ensure permanent US LEO presence following the eventual retirement or failure of ISS, it behooves both NASA and Congress to consider the potential roles of our international partners. Would Congress permit European companies to participate in a pilot? In the eventual program of record? If not, we can expect to lose partners for human exploration.
   b. Do you think such a program could also be used to demonstrate technologies and capabilities for a beyond-LEO habitat, necessary for missions to the Moon, Mars, and beyond?
      Sommerer: Yes. Please see my answer to Chairman Babin's question #2. Note also that LEO habitats cannot be used to develop radiation mitigation strategies for deep space habitats, for the same reasons that ISS cannot. Radiation mitigation is a critical issue for human exploration beyond LEO, but systems must be tested and demonstrated beyond LEO. Finally, note that for the foreseeable future, the NAS Committee on Human Spaceflight holds the view that there is no "beyond" past Mars.

3. The current flight rate of the SLS is highly concerning to me. Even Bill Gerstenmeyer has stated the SLS needs to launch once a year to maintain operational readiness.
   a. What potential issues arise when flights are planned only once every three years?
      Sommerer: The primary issue is that, given probable employee turnover, there is little ascent of a "learning curve" in manufacturing the SLS. In effect, each copy is built

"from scratch." There are no economies of scale, and reliability will suffer, which in such an expensive system is a major problem. Other, learning-curve-related problems also arise, such as operator proficiency and readiness to problem-solve in "Apollo 13-like" scenarios.

b. In a once-a-year launch cadence what is necessary to alleviate these concerns?
Sommerer: Although extensive computer-based simulation may help to alleviate some of these learning-curve-related concerns, it is important to note that even a once-a-year launch cadence is unprecedentedly low relative to the nation's previous experience with human-rated systems. The Space Shuttle flew 135 times over 30 years, for an average cadence of 4.5 flights per year. Two of those flights, obviously, resulted in loss of the crew, and substantial delays to resuming flight cadence. During the "space race" there were 30 attempted crewed launches (including Mercury, Gemini, and Apollo) between 1961 and 1972, for an average crewed mission cadence of 2.7 flights per year (there were also a number of robotic flights). Two of those flights attempts were mission failures, one resulting in loss of the crew. I would be extremely surprised if a once-a-year cadence, even with the advances in computer-aided simulation, could achieve similar success.

4. What potential science, planetary, or national security payloads could launch on the SLS in order to maximize the utility of missions and contribute to an increase in launch cadence?
Sommerer: Please see my answer to Chairman Babin's question #5. I would further note that the use of SLS for non-human missions conflates two competing agendas. Use of SLS for non-human missions could increase the flight cadence, but would be unlikely to materially reduce the cost of the system. Thus the other users of the SLS are doubly burdened with an affordability issue due to the costs of human-rating, and the intrinsic cost of the lift capacity of SLS. Unless Congress materially increases the budget for SLS manufacture, to "immunize" other users from increased launch costs, other potential users will resist. Within NASA, and absent guidance from Congress, this is likely to further erode the science budget in favor of the human exploration budget. For the USAF and NRO, it is unlikely that they will launch on SLS, for reliability and availability reasons, especially at a time when they are trying programmatically to "disaggregate" large and highly expensive systems to increase survivability.

5. Is it concerning that NASA has not announced even general plans for missions beyond EM-2?
Sommerer: It is extremely bothersome. The cumulative cost of SLS/Orion is enormous. For NASA not to have concrete plans for what to do with it, and when to do it, at this point should be a matter of grave concern. This is one reason that the NAS Committee on Human Space Flight strongly recommended a "Pathway" approach to human exploration beyond LEO. Both Associate Administrator Gerstenmaier's statement about a once-a-year launch cadence, and the initial flight manifest, which lacked missions after EM-2 were available while the Committee was still operating, and the Committee noted the credibility issues raised by this uncomfortable juxtaposition in its report, issued in June 2014, i.e. almost two years ago.

6. How can NASA continue to leverage public-private partnerships, such as commercial cargo and commercial crew, as the human exploration program extends beyond LEO?
Sommerer: I must admit that I am skeptical of the ability to use public-private partnerships, as opposed to normal contracting, for human exploration beyond LEO. Whereas commercial

cargo has gone relatively smoothly, and affords private industry opportunities to develop systems that provide increased competition, and one hopes, lower costs, for lift to LEO, we are not nearly so experienced when it comes to fee-for-service with human-rated systems. Perhaps the emerging space tourism industry, as well as commercial crew, will provide important insights as human spaceflights on privately developed systems take place. If there are mission failures, particularly involving loss of life, I think it will have a profoundly chilling effect on NASA using "private" systems. In any case, it seems to me that long-term viable public-private partnership opportunities will be possible only when non-NASA applications are a significant part of the prospective market. This does not seem to be the case for beyond-LEO human exploration. The consequences of a loss-of-crew failure to the NASA human exploration program have always been dire and threatening. For such an event to be traceable to a much less regulated contracting arrangement than we have traditionally followed between NASA and its contractors would potentially threaten the very existence of the human exploration program.

Questions submitted by Ranking Member Edwards:

1. In your prepared statement, you state that…. To what extent is NASA focusing on the top three technology priorities identified in the Pathways report —Mars entry, descent, and landing; radiation safety; and in-space power and propulsion?
   Sommerer: NASA has a substantial effort underway, through STMD, on a particular approach to Mars EDL: the Low-Density Supersonic Decelerator has been been flight-tested twice using the Earth's upper atmosphere as a surrogate for the thin Mars atmosphere. This is a promising program, that nevertheless has a long way to go (including robotic tests at Mars) before it could be relied upon to land a human crew on Mars' surface. With regard to radiation safety, the NASA Human Research Program continues to accrue evidence to quantify increased risk of cancer due to space radiation. Other potential health risks, such as loss of cognitive ability caused by neuron destruction, are not being quantified to my knowledge. Finally, I am unaware of any tests or development programs aimed at mitigation (also note that the Technical Panel is skeptical about the possibility of mitigating galactic cosmic rays, as opposed to solar particle radiation). NASA would probably claim that development of solar electric propulsion for use in ARM is intended address the in-space power and propulsion recommendation. However, (see my response to Chairman Babin's question #1), the SEP effort dilutes the effort that will be required to send humans to Mars. NASA apparently envisions SLS (second upgrade) as the propulsion system for the crew. However, there are several critical developments that will be needed before that is possible, notably the two upgrades required to produce 150MT lift. Also critically important is the development of zero-boil-off storage for cryogenic chemical propellant; this technology will be necessary to preserve the fuel needed to return the crew to earth over the course of the very long mission duration. To my knowledge, NASA is not pursuing this latter technology with any vigor.

   I note that NASA has a very large number of subcritical efforts addressing many aspects of spaceflight technology; the main product of this very diffuse effort is briefing slides. Use of a pathways approach, with concomitant downselection of necessary technologies, would permit concentration on those systems that will support the pathway.

   Finally, I am concerned that NASA appears to be implicitly committing to chemical propulsion for Mars. I am are skeptical that this is the right approach. Nuclear thermal propulsion (NTP) seems a much more reasonable (and enabling) selection, and the Mars DRA 5 design reference architecture that the Technical Panel studied in detail assumed NTP. I recognize that NTP is a very ambitious and difficult technology development program. Indeed, "no single space technology project in this period will be more impressive to humankind, or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish" to paraphrase President Kennedy's May 25, 1961 speech to Congress which in many ways was the foundation for this hearing. In fact, it may be that the development of NTP is the ultimate test of whether we, as a nation, are serious about human space exploration, or whether we are just arranging "stunts."
   a. Has NASA discussed the Pathways report with your committee?
      Sommerer: Administrator Bolden, Associate Administrator Lightfoot, and various members of their staff were briefed on the Committee report on June 3, 2014. Associate Administrator (HEOMD) Gerstenmaier, was not present, and to my knowledge never was briefed by the Committee, and certainly never engaged the Technical Panel. Gerstenmaier, however, did address comments on the Pathways report to the NAS Aeronautics and Space Engineering Board this past April, and earlier commented to

Aviation Week & Space Technology (June 23, 2014) that although the report is very "well-written," it is not very realistic. I therefore assume he read the report. I also assert that it is NASA's current "plan" for sending humans to Mars that is not realistic.

b. Is NASA taking steps to address the overall list of 15 high-priority technical capabilities that your committee identified? If not, why not?
Sommerer: As noted earlier, NASA is substantially engaged in addressing heavy lift (SLS), and human health (Human Research Program), as well as Mars EDL. In addition, I am aware of small efforts that address various aspects of some of the other 15 high priority technical capabilities, such is in-situ-resource-utilization and habitats. However, I would not characterize these as major efforts likely to enable human missions to Mars within 20 years. Finally, there are a number of other high priority technologies that, to my knowledge, are not being addressed beyond the briefing slide stage, such as radiation protection, alternatives to cryogenic chemical propulsion, surface power systems. and perhaps most disturbingly, high-reliability ECLSS. I am not in a position to address the "why not?" portion of the question, except to note that NASA is underfunded (and under directed) to meet the Administration's stated timetable for Mars.

c. What needs to happen on NASA's technology efforts now in order to make maximum progress toward the goal of sending humans to Mars?
Sommerer: 1) adopt a pathways approach with specific intermediate and final destinations, preferably with associated intended dates of attainment; 2) explicitly downselect technologies needed to execute the pathway (and perhaps sustain a very limited number of alternatives if the most speculative selected technologies prove unworkable); 3) focus available resources on the necessary technologies and discontinue spending on technologies (and infrastructure) that do not support the pathway. (A specific example of things that we should not do in the future is the completion of the A-3 test fixture at the Stennis Space Center, after the program it was designed to support was cancelled, and for which no alternative purpose was identified; clearly Congress has a critical role to play in establishing and maintaining the momentum of a realistic human exploration program).

2. Is there agreement on the technologies that should be demonstrated on the International Space Station in order to reduce risk in their application to human exploration beyond LEO? Do NASA's plans for the ISS include such demonstrations in a timely manner?
Sommerer: Unfortunately, the ISS is not a feasible environment for investigation and demonstration of many of the potentially necessary technologies (radiation protection, NTP, high power SEP, ISRU, mitigation of psycho-social effects due to light-time delays in communicating with Earth, etc.). The ISS, and its vicinity, can obviously be used to support the development of high-reliability ECLSS, in-space habitats (less radiation protection) and crew health risks associated with zero-g. I believe NASA is addressing the latter issue vigorously. NASA is beginning to address habitats, supported strongly by the private sector. I am concerned that the priority for high-reliability, relatively maintenance-free ECLSS is not nearly high enough.

3. Regarding a human exploration strategy for Mars, what is the appropriate balance between the level of detail included versus the flexibility that is needed to make decisions that are informed by new information?
Sommerer: Obviously, we do not want to paint ourselves into a corner. But we do need a plan, and preferably one based on a specific, agreed-to pathway. That will inform which technologies need to be developed, and which do not. It will minimize the development of

systems that do not support the pathway. It will enhance Executive and Congressional oversight of the overall enterprise.

a. In addition, do we need a decision on a baseline architecture now, and if not, when?
Sommerer: Perhaps not now, in the sense that we are at the end of an Administration. But we do need such a decision as soon as possible, together with the development of a commitment between the Executive and Legislative Branches, as well as development of the necessary management approaches to ensure that we stick with the plan and the associated architectures over the long haul.

b. Do we need a design reference mission? If so, how far in advance of a mission to land humans on Mars do we need it?
Sommerer: We need a set of design reference missions (or architectures). We need one for each mission class on the selected pathway. We need them as soon as possible to focus our analysis, efforts and resources, and management attention.

4. When could the Nation expect to achieve the goal of sending humans to Mars under
   a. current budgetary spending on human exploration (including ISS)?
   Sommerer: In my opinion, realistically, never.
   b. inflationary increases?
   Sommerer: This and the following answer are addressed in the Pathways report, based on a cost analysis approach that reflects cumulative experience with NASA technology and system development. The answers further assume that a pathways approach is used, with appropriate management and resource focus, and the political commitment to stick to a particular pathway. The ranges indicated reflect the variation between the different pathways analyzed by the Technical Panel, the retirement date of the ISS, and the nation's tolerance for developmental and operational risk. The Panel considered two scenarios for the ISS, one with its retirement (effectively, removal from NASA's budget — the ISS could conceivably be operated and funded privately for some time) in 2020; the second scenario assumed retirement in 2030 (NASA has indicated that the system "design life" will permit operations through 2028 without significant recapitalization). The Panel's estimate of the first human Mars landing under an inflation-adjusted scenario is in the range 2037-2054.
   c. 5% annual increase in spending on human exploration?
   Sommerer: The Technical Panel conducted a detailed analysis for a scenario where the human exploration budget increased at 4x the rate of inflation through approximately 2025 (after that, the human exploration budget would be "roughly" flat in constant dollars) For recent US inflation, that corresponds to an annual budget increase of between approximately 4% and 10%. Under this scenario, and the assumptions listed under b. above, the Panel's estimate of the first human Mars landing is in the range 2033-2039.

   (I should note that NASA uses an inflation rate focusing on NASA-relevant costs, rather than the broader Bureau of Labor Statistics Consumer Price Index. The Technical Panel felt that the use of the NASA rates would introduce specious precision into our results, so this answer reflects CPI. Finally, note that the predictions above, reflecting a pathway approach, should be delayed by the two years since the report's issue, during which we have decidedly not been using such an approach.)

5. Your prepared statement noted....it is your view that includes the surface of the Moon "is one obvious possibility." Please elaborate on your comment.

Sommerer: As Dr. Spudis, who also testified before the Subcommittee on February 3, 2016, noted, the Moon is "interesting, useful, and close." It certainly offers the ultimate in credibility as a destination for human spaceflight—we've already been there. Our traditional human spaceflight partners, notably Europe and Japan, have expressed a decided interest in a more extensive human exploration (and development) of the Moon than was feasible during the initial reconnaissance accomplished by Apollo. In addition, from my perspective, there are very significant uncertainties in whether we will be able to send humans to Mars (and safely return them to the earth), particularly if we are unable or unwilling to develop enabling technologies like NTP and nuclear surface power. Would it not be better to be operating visibly (in both the figurative and literal senses) on the Moon, learning more about how successful humans can be off their mother planet, than to strive for Mars and fail, leaving no human presence (or US presence, at least) in space beyond LEO? (I also note that the development of NTP on earth represents an environmental risk and a regulatory nightmare; however, development and test of this technology in the vacuum of cis-lunar space—including the surface of the Moon—would mitigate those particular problems significantly.)

Finally, I note that some new considerations arise given that the Moon is probably "useful" as Dr. Spudis puts it. The 1967 treaty on "Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies" forbids any party from claiming a celestial resource, which is "not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means." Based on our experience with the United Nations Convention on the Law of the Sea, we may rightfully suspect that not all Parties to the Space Treaty will interpret it in the way that we do. Our lack of presence on the Moon, however, would allow for establishment of "facts in the sky" that might be detrimental to our long-term interests from both economic and national security perspectives.

6. In your prepared statement you made the point that… Please elaborate on your view that the development of electric propulsion is not needed for a Mars human mission. What alternative approach did the Technical Panel support and why?
Sommerer: SEP could be used to preposition a number of systems in the DLA 5 architecture, such as the surface habitat, the ISRU unit (responsible for generating the oxygen for crew use on the surface of Mars, and for use as oxidizer in the ascent stage), a surface power source, etc. However, SEP at the scale proposed is not capable of sending the crew to the vicinity of Mars in a timely fashion (to mitigate the health impacts of time in zero g and exposure to space radiation, and to reduce the amount of consumables the crew needs to sustain them through the cruise). Thus, NASA is developing two completely independent technologies for transport to Mars, one fast and one slow. Given the concerns about overall development budget, SLS launch rates, and the necessity of minimizing transit time for the crew, why not use a single (fast) system to do the whole job? There is nothing about the prepositioned materiel that suggests it cannot be prepositioned by SLS. As noted previously, the Technical Panel made extensive use of NASA's DRA 5 architecture, which actually employed NTP at the propulsion system. (Also note that, as outlined in my answer to Ranking Member Edwards' question #1, NTP is a much more enabling technology than chemical propulsion. Relative to the long transit time to Mars, chemical propulsion is, in fact, also a "slow" technology. SLS would still be needed for lift of heavy systems, including an NTP system, to LEO or wherever the Mars craft would be assembled or marshaled. Thus is does not dilute the development of a Mars mission.) I also note that robotic missions, like

DAWN and the technology demonstration mission Deep Space 1 both made effective use of SEP. SEP is not a bad technology. But it does dilute the development needed to send humans to Mars.

7. Radiation exposure and effects is one of the top risks of sending humans to Mars. How should finding a way to mitigate this risk be incorporated into a pathway or architecture for sending humans there?
Sommerer: There are two types of radiation involved. The first, solar particle radiation, is most dangerous in the context of solar particle events (such as coronal mass ejections), which have the potential to kill an unprotected crew (the Apollo astronauts faced this risk essentially unprotected, but fortunately no major solar particle events occurred during their missions to the vicinity of the Moon). Shielding is effective against this type of radiation, and there is much discussion of using stored water, which is necessary anyway for crew support, as the shielding material. Habitat development needs to incorporate this, or some other, shielding technology. The proof of such shielding technology needs to take place (perhaps robotically, with non-human subjects) outside the earth's inner magnetosphere, for example in cis-lunar space. This is another motivator to include the Moon in a US pathway.

The second type of radiation is galactic cosmic rays (GCR). These are particles accelerated to very high energies (10^9-10^{20} electron volts, as opposed to solar protons, the hazardous ones of which typically have energies in the millions of electron volts) by astrophysical processes outside our solar system, and include a small proportion of particles with high atomic numbers, and which may therefore be very highly ionized. These have an extremely destructive effect on human tissue, for example killing multiple neurons outright, or seriously damaging the DNA in many cells. Unfortunately, for these particles, shielding can make them even more dangerous, because a GCR impacting shielding material will typically produce a cascade of many other energetic particles. Relatively small amounts of water, or small (light) amounts of metal, will not be effective as shielding, and since the shielding is necessary for protection from solar particle events, crews will be exposed to the primary and secondary effects of GCR. (Ironically, the best time for humans to fly to Mars is during solar maximum, when solar particle events are more dangerous, because the Sun's magnetic field will reduce the number of GCRs in the inner solar system).
The danger from GCR, coupled with current propulsion systems (more particularly the long transit times resulting from them) is one of the principle reasons that Mars is just on the edge of feasibility. The primary means of protecting a crew from GCR is to minimize flight time for the crew, which is one of the reasons to seriously consider alternative propulsion schemes than chemical propulsion (even NASA is not considering SEP for crew propulsion).

8. Is NASA on track to mitigate identified human health risks such as radiation exposure by the estimated timeframe for sending humans to Mars (in the 2030s)?
Sommerer: In my opinion, no. There is much optimism within NASA that advances in biology and medicine will become available to mitigate the risks posed by radiation. A previous NASA administrator was fond of asserting that "there'll be a pill you can take to undo the damage caused by radiation." I share NASA's confidence that advances in the biological sciences may reduce the risks to human crews in deep space, as the level of progress and investment are both high (in particular, much higher than NASA can fund for purposes specifically related to space travel). However, I am skeptical about space radiation risks being swept away by pharmacology. For the foreseeable future, astronauts in deep space will be subject to grave health risks. Their lives may be shorter, they may develop acute

health problems that are extremely difficult to treat on long journeys, and they may be become cognitively impaired after long flights in deep space. This is an issue that needs to be an explicit part of, and a high priority within, any feasible plan for human exploration beyond LEO.

Answers to Questions for the Record

Paul D. Spudis (spudis@lpi.usra.edu)
31 March, 2016

Questions submitted by Rep. Brian Babin, Chairman, Subcommittee on Space

1. The Director General of the European Space Agency has been vocal about his support for an international lunar village to replace the International Space Station. What benefits do you see from such an endeavor?

a. Should NASA be exploring participation in such a project?

b. Would the existing ISS Intergovernmental Agreement be appropriate structure for engaging on such an endeavor?

A. American participation in an international effort to establish a presence on the Moon carries many benefits and a few potential pitfalls. I favor involvement with the European effort, largely because their politico-economic outlook is similar to ours – pluralistic politics and free markets. It makes sense for countries that subscribe to these values to join together on the space frontier. We need this presence on the Moon and in cislunar space to develop the resources of the space frontier and use them to create new space faring capabilities and to ensure that it is done so as to provide the maximum benefit and opportunity for all.

NASA is already participating with Europe in that the Europeans are making the service module for the Orion spacecraft. Similar partnering and cost sharing could be undertaken to build landers and lunar surface hardware as well. The existing ISS agreement, while largely beneficial and successful, should be reviewed and considered carefully before applying it directly to a new international lunar base effort.

2. In your testimony, you said, "we pretend we are on a 'Journey to Mars' but in fact, possess neither the technology nor the economic resources necessary to undertake a human Mars mission now or within the foreseeable future." How did the cancellation of Constellation, and the starvation of funding that preceded that cancellation, impact our ability to explore deep space?

A. The real problem was the termination of the Vision for Space Exploration, a bipartisan strategic vision that included the Moon and Mars with an emphasis on developing the resources of near-Earth space. The abandonment of the Vision left the nation with no destination, no means to do anything, created organizational chaos and has led to our current space policy muddle. Constellation was not really "cancelled," but transformed (by the Congress in the 2010 Authorization) into the Orion/SLS system. The best single thing the Congress could do now is to make the lunar surface a priority destination as part of the alleged "Journey to Mars." Unless we have a clear, near-term, reachable destination – and a set of achievable milestones and beneficial activities – we will continue to flounder, spending significant sums "on space" but without anything of lasting value to show for it.

3. How do you think the upcoming SLS and Orion' missions will resonate with the American people, and people around the world? What are the potential "soft power" and secondary impacts of these high profile missions?

A. I doubt that the next couple Orion/SLS missions will do much for American standing in space power, but they will demonstrate that by building significant hardware, we are committed to undertaking real human missions beyond LEO. Considering the doleful effects of the last 7 years of indifferent and irrelevant space activities, that would be a significant advance. Nonetheless, to regain our status as a world leader in space, we must adopt a true long-term strategy, one that incrementally builds capability. NASA wants to talk about Mars missions forever, but talk doesn't accomplish anything. By returning to the Moon and using its resources to create new space capabilities, we not only open space to human permanence, but lay the groundwork for future missions to Mars as well.

4. What are the benefits of the technology development resulting from the development of exploration systems to U.S. industry and the taxpayers? Looking ahead, what are the primary benefits that may flow from NASA's development of SLS, Orion, deep space habitats, in space propulsion, and landers?

A. While I acknowledge that many technical "spin-off" benefits exist, they are hard to quantify and cataloging them never convinces the unbelievers. I think that the real value of deep human spaceflight is to be certain America participates in any theater of future human endeavor. Establishing a space-based transportation system that can routinely access all the points in cislunar space (i.e., the volume of space between Earth and Moon) allows us to visit, service, and maintain all of our satellite assets there, where 95% of them reside. In addition, we will be able to build complex, large structures in high Earth orbit (e.g., geosynchronous), enabling complete global communications with enormous bandwidth. The myriad practical benefits of a permanent presence in cislunar space will sell that effort on its own merits.

5. Orion is being built to fly deeper into space than Apollo and return at higher speeds. It carries an advanced life support system that enables crews to exercise, provides radiation protection, and can go to Mars with the addition of a deep space habitat. Given the capabilities of the vehicle, and the lifting power of the SLS, what missions can you envision that would advance human exploration of our solar system while opening the door to human exploration-enabled science?

A. Actually, Orion is optimized for missions to and within cislunar space, as befits its heritage from the defunct Constellation architecture. As such, I believe that the best use of this new capability is to re-instate the lunar surface as a primary objective and use the Orion/SLS hardware to launch and emplace an outpost on the Moon. Such an outpost, located at one of the lunar poles (or two outposts at both poles), could harvest the known deposits of water ice, which can be converted into rocket propellant and can also support human life. Developing the resources of the Moon will allow us to build a true space faring infrastructure, giving us access to all destinations beyond LEO.

Questions submitted by Rep. Jim Bridenstine

1. The FY 2016 Omnibus Appropriations bill directed NASA to have a habitat ready for deployment by 2018. Will NASA need to partner with the private sector in order to make this date?

A. That timescale is rather aggressive and it may be difficult to reach under any circumstance. However, at least one private company (Bigelow) has developed habitat modules that might be ready by the deadline. Additionally, NASA possesses a leftover ISS habitat module that was not used on the space station – it could be converted into a deep-space habitat with relatively minimal effort. In any case, if this deadline is to be taken seriously, the Congress should be prepared to fund it at an appropriate level.

2. Congress just extended the life of the ISS through 2024, but NASA needs to begin thinking about the next steps to make sure the United States maintains a permanent presence in LEO.

a. Do you think establishing a commercial habitat pilot program in order to test the viability of commercial habitats as an eventual replacement of the ISS would be a prudent step for NASA to take?

b. Do you think such a program could also be used to demonstrate technologies and capabilities for a beyond-LEO habitat, necessary for missions to the Moon, Mars, and beyond?

A. For question a), I'm not sure that tasking NASA to do this will be an effective strategy. There are efforts currently underway to create commercial LEO laboratory facilities and these might be ready on the appropriate timescale. For question b), I absolutely agree. Many different in-space technologies could be tested and developed in a commercial LEO space laboratory, including cryogenic fluid transfer, cracking of water into its elemental components (hydrogen and oxygen), freezing these gases into liquids, and using the derived cryogens to fuel trans-LEO spacecraft. Such technology is critical to the long-term use and habitation of space. One way to conduct this research might be for NASA to fund independent contracts and grants to develop the needed skills using commercial space facilities.

3. The current planned flight rate of the SLS is highly concerning to me. Even Bill Gerstenmaier has stated the SLS needs to launch once a year to maintain operational readiness.

a. What potential issues arise when flights are planned only once every three years?

b. Is a once a year launch cadence what is necessary to alleviate these concerns?

A. I am greatly concerned also and the Congress should take steps to ensure that this low level of activity is not allowed to proceed. Mandating missions to the lunar surface is one way to keep up a respectable flight rate and depending upon how it is structured, will not necessarily involve large amounts of additional funding. The problem created by flying SLS only once every three years is that you still need a large, trained workforce and they must remain employed, even when they aren't doing anything. Thus, total program costs are greater, for less accomplishment. If

we are serious about a human deep space flight program, we need a higher flight rate. Ideally, more than one flight per year is desirable – two to three per year is optimal.

These SLS launches need to send something to somewhere. The obvious beneficial destination is the lunar surface. Congress should mandate that a return to the Moon is the next major goal for NASA's human spaceflight program. This does not "negate" the Mars mission – in fact, human presence on the lunar surface enables it, by producing the propellant needed for interplanetary travel. I have serious doubts whether we will ever get to Mars without first returning to the Moon, for the wide variety of reasons outlined in my submitted written testimony.

4. What potential science, planetary, or national security payloads could launch on the SLS in order to maximize the utility of missions and contribute to an increase in launch cadence?

A. With a payload capacity of 70 metric tons (SLS Block 1), this launch vehicle is capable of many different missions, including elements of a lunar outpost, large planetary probes (surface rovers and orbiters), complex Earth observation satellites, and a variety of national security satellite payloads. I believe that the requirements of creating a lunar outpost would be more than enough to keep the SLS launch system operating at full capacity.

5. Is it concerning that NASA has not announced even general plans for missions beyond EM-2?

A. It is, but it is also not surprising. Because NASA has no clear near-term (within the next 5-10 years) destination of any value, they cannot imagine what Orion/SLS missions they might fly. The engineers are precluded from planning for lunar surface missions by agency policy. Therefore, we get silence.

6. How can NASA continue to leverage public-private-partnerships, such as commercial cargo and commercial crew, as the human exploration program extends beyond low Earth orbit?

A. Assuming that these programs are adjudged successes, it should be a simple matter to extend their purview beyond LEO into cislunar space as the agency moves outward. One example would be to contract with a commercial provider to deliver payloads to deep space, for example, a habitat at one of the L-points or to the lunar surface. Such a program could be structured in a manner similar to the existing contracting vehicles.

Questions submitted by Rep. Donna Edwards, Ranking Member, Subcommittee on Space

1. In your prepared statement, you noted that going to the Moon and cislunar space *"is an*

incremental, affordable and useful strategic direction". **At the same time your statement noted that *"to access the various levels of cislunar space, we need...a permanent space faring infrastructure...deep space habitats, power stations, and fuel depots."* How do you reconcile having an incremental and affordable cislunar program while also developing a large, permanent spacefaring infrastructure? Is there a risk that a significant investment in developing permanent lunar operations could detract from achieving the long-term goal of sending humans to the surface of Mars, as directed in the House-passed NASA Authorization Act of 2015?**

A. By creating the space transportation system in small steps (affordable), which can be operated in conjunction with each other (cumulative) and each of which build upon and adds capability to the system as a whole (incremental). The system to which I am referring consists of orbital and surface elements. Stations and fuel depots in low earth orbit and around the Moon can accept propellant manufactured on the lunar surface (made from the water ice that we now know exists at the poles). Staging nodes accept spacecraft from different locations and route them to their next destination. Service facilities store and transfer propellant, generate electrical power, and refurbish transferring spacecraft. These pieces make up the transportation system. The system will not only access the lunar surface, but also any other point in cislunar space. Its existence enables future missions to the planets, including Mars.

We are told by some space advocates that the building of a lunar outpost precludes a human Mars mission. In fact, the opposite is more nearly true. A fully fueled, spacecraft for a human mission to Mars will weigh in excess of one million pounds; fully 80% of this mass is rocket propellant, the vast bulk of which is expended in the first 30 minutes of the journey (the trans-Mars injection burn). It makes little sense to launch all of this mass from the surface of the Earth, the deepest gravity well in the inner Solar System. I contend that it is better to obtain this fuel from the Moon, which has 1/6 the gravity of the Earth. By mining the lunar poles for water, we make fuel not only for the cislunar space transportation system, but also for future missions to Mars as well.

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I thank the committee for inviting me to testify and for asking me these follow-up questions. I am available to provide any additional assistance and information that you may require.

Additional information on the topics covered here can be found at the following links:

http://www.spaceref.com/news/viewnews.html?id=1376

http://www.spudislunarresources.com/Bibliography/a/a40.pdf

http://www.spudislunarresources.com/Papers/SpudisPaulD.pdf

http://www.spudislunarresources.com/Papers/12SpudisNDU.pdf

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