

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

HEARING CHARTER

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

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

PURPOSE

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

WITNESSES

- **Lt. General Thomas P. Stafford**, USAF (Ret.); Member, National Academy of Engineering; Chairman, NASA ISS Advisory Committee; Pilot, Gemini 6, Commander, Gemini 9; Cdr. Apollo 10, Cdr. Apollo/ Apollo-Soyuz Test Program; Former USAF Deputy Chief of Staff for Research, Development and Acquisition
- **Mr. A. Thomas Young**, Former Director, NASA Goddard Space Flight Center, Former President and Chief Operating Officer, Martin Marietta Corporation

OVERARCHING QUESTIONS

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

BACKGROUND

The year 2019 marks 50 years since Americans sent the first humans to the surface of the Moon on the Apollo 11 mission, a monumental event of cultural, technological, and economic significance. The Apollo program continued for three more years until its final mission, Apollo 17, in 1972. While the United States continued to advance a human spaceflight program—developing and operating the Space Shuttle; developing, assembling, and continuously operating the International Space Station; and initiating the ongoing development of the Orion crew vehicle and Space Launch System—the nation has not explored deep space¹ with humans since the Apollo program ended over 40 years ago.

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

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

Pioneering the Space Frontier (1986)³

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

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

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

¹ “Deep space” generally means beyond low Earth orbit (LEO), about 1,200 miles above the Earth’s surface.

² P.L. 109-155, The NASA Authorization Act of 2005; P.L. 110-422, The NASA Authorization Act of 2008; P.L. 111-267, The NASA Authorization Act of 2010; and P.L. 115-10, The NASA Transition Authorization Act of 2017.

³ “Pioneering the Space Frontier: The Report of the National Commission on Space,” May 1986. Available at:

https://www.nasa.gov/pdf/383341main_60%20-%2020090814.5.The%20Report%20of%20the%20National%20Commission%20on%20Space.pdf

Two additional economic thrusts were included:

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

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

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

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

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

America at the Threshold (1991)⁴

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

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

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

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

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

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

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

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

The pitfalls identified were:

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

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

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

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

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

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

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

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

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

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

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

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

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

The Committee identified five options for the human spaceflight program that considered the current programs of record, budgetary constraints and exploration goals. One was a baseline program that would implement the current program of record⁹ within the existing budget. Two of the options were constrained to a flat or decreasing budget from 2010 to 2014. The fourth option focused on the Moon first, while the fifth option offered a flexible path focused on exploration as a strategy and could include lunar flybys, visits to Lagrange points and near-Earth objects.

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

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

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

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

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

The NASA Authorization Act of 2010¹¹ directed NASA to engage the National Academies for a study that would review “*the goals, core capabilities, and direction of human spaceflight.*” In fulfilling that direction, in June 2014, the National Academies released *Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration*, referred to hereafter as *Pathways*, a consensus study report of the Committee on Human Spaceflight.

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

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

¹¹ Section 201, P.L. 111-267.

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

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

- I. Commit to designing, maintaining, and pursuing the execution of an exploration pathway beyond low Earth orbit toward a clear horizon goal.*
- II. Engage international space agencies early in the design and development of the pathway on the basis of their ability and willingness to contribute.*
- III. Define steps on the pathway that foster sustainability and maintain progress on achieving the pathway’s long-term goal of reaching the horizon destination.*
- IV. Seek continuously to engage new partners that can solve technical or programmatic impediments*
- V. Create a risk-mitigation plan to sustain the selected pathway when unforeseen technical or budgetary problems arise. Such a plan should include points at which decisions are made to move to a less ambitious pathway (referred to as an “off-ramp”) or to stand down the program.*
- VI. Establish exploration pathway characteristics that maximize the overall scientific, cultural, economic, political, and inspirational benefits without sacrificing progress toward the long-term goal.”*

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

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

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

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