

NASA: PAST, PRESENT, AND FUTURE

HEARING BEFORE THE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY HOUSE OF REPRESENTATIVES ONE HUNDRED FIFTEENTH CONGRESS

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NASA: PAST, PRESENT, AND FUTURE

THURSDAY, FEBRUARY 16, 2017

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

The Committee met, pursuant to call, at 10:08 a.m., in Room 2318, Rayburn House Office Building, Hon. Lamar Smith [Chairman of the Committee] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

Congress of the United States
House of Representatives

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

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NASA: Past, Present, and Future

Thursday, February 16, 2017

10:00 a.m.

2318 Rayburn House Office Building

Witnesses

Hon. Harrison Schmitt, Apollo 17 Astronaut, Former United States Senator

Lt. Gen. Thomas P. Stafford, Gemini VI, Gemini IX, Apollo 10, Apollo-Soyuz
Test Project Astronaut; Chairman, NASA International Space Station Advisory
Committee

Dr. Ellen Stofan, Former NASA Chief Scientist

Mr. Tom Young, Past Director, Goddard Spaceflight Center; Past President/COO,
Martin Marietta; Past Chairman, SAIC

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

Charter

TO: Members, Committee on Science, Space, and Technology
FROM: Majority Staff, Committee on Science, Space, and Technology
DATE: February 16th, 2017
SUBJECT: Full Committee Hearing: “NASA: Past, Present, and Future”

On Thursday, February 16th, 2017 at 10:00 a.m. in Room 2318 of the Rayburn House Office Building, the Committee on Science, Space, and Technology will hold a hearing titled, “NASA: Past, Present, and Future.”

Hearing Purpose

This hearing will review NASA’s past portfolio of missions, evaluate existing exploration programs, and provide a venue for consideration of potential bold and innovative missions going forward.

Witnesses

- **Hon. Harrison Schmitt**, Apollo 17 Astronaut, Former United States Senator
- **Lt. Gen. Thomas P. Stafford**, Gemini VI, Gemini IX, Apollo 10, Apollo-Soyuz Test Project Astronaut; Chairman, NASA International Space Station Advisory Committee
- **Mr. Tom Young**, Past Director, Goddard Spaceflight Center; Past President/COO, Martin Marietta; Past Chairman, SAIC
- **Dr. Ellen Stofan**, Former NASA Chief Scientist

Staff Contact

For questions related to the hearing, please contact Mr. Tom Hammond, Staff Director, Space Subcommittee, Mr. G. Ryan Faith, Professional Staff Member, Space Subcommittee, or Mr. Jonathan Charlton, Policy Assistant, Space Subcommittee, at 202-225-6371.

Chairman SMITH. The Committee on Science, Space, and Technology will come to order. Without objection, the Chair is authorized to declare recesses of the Committee at any time.

Welcome to today's hearing entitled "NASA: Past, Present, and Future." I'll recognize myself for an opening statement and then the Minority Member.

NASA has a storied past. The witnesses before us today are proof of that. They personify the accomplishments of our American space program. Joining us today, we have two legendary astronauts, two accomplished scientists, two preeminent engineers, three space advisory body members, leaders from both the private and public sector, and accomplished managers. We have the only scientist to walk on another celestial body, a test pilot that has flown 120 different types of aircraft and three different space vehicles, a revolutionary leader in stealth technology development, a former Senator, a former Lieutenant General, a former NASA Center Director, the Mission Director for the first robotic landing on Mars, and NASA's former Chief Scientist, all in four people. Their impressive accomplishments give them the credibility to discuss the future of our space program.

We stand at a crossroads. Sir Isaac Newton said, "I do not know what I may appear to the world, but to myself I seem to have been only like a boy playing on the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me."

Today, as we consider the next steps of the space program, we are all like that boy or girl. Presidential transitions offer the opportunities to reinvigorate national goals. They bring fresh perspectives and new ideas that energize our efforts. Now is the time to reaffirm our support for the bold visions and commitments that will shape America's future in space.

The NASA Transition Authorization Act of 2017 is the culmination of many years' discussions and hopefully will soon pass the Senate and House. And it perhaps will pass the Senate tomorrow. This legislation has two goals. First, it reiterates the importance of maintaining NASA's continuity of purpose. The National Research Council's "Pathways" report, the Aerospace Safety Advisory Panel's recent reports, and numerous outside advisory groups and associations have all highlighted the significance of continuity. Without it, our space program will be left adrift and rudderless.

Second, the bill allows the President to introduce a fiscal year 2018 budget request that reflects his priorities. With a fresh perspective, the White House will be able to work with the new Congress to implement the goals and initiatives necessary to continue our leadership in space. Our hearing today provides an opportunity to understand fundamental challenges before the new Administration and Congress. And we will explore possible directions for our space program that will benefit and inspire the American people.

[The prepared statement of Chairman Smith follows:]



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

For Immediate Release
 February 16, 2017

Media Contact: Kristina Baum
 (202) 225-6371

Statement of Chairman Lamar Smith (R-Texas)
NASA: Past, Present, and Future

Chairman Smith: NASA has a storied past. The witnesses before us today are proof of that. They personify the accomplishments of our American space program.

Joining us today, we have two legendary astronauts, two accomplished scientists, two preeminent engineers, three space advisory body members, leaders from both the private and public sector, and accomplished managers.

We have the only scientist to walk on another celestial body, a test pilot that has flown 120 different types of aircraft and three different space vehicles, a revolutionary leader in stealth technology development, a former Senator, a former Lieutenant General, a former NASA center director, the mission director for the first robotic landing on Mars, and NASA's former chief scientist, all in four people.

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Our hearing today provides an opportunity to understand fundamental challenges before the new administration and Congress.

And we will explore possible directions for our space program that will benefit and inspire the American people.

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Chairman SMITH. Now, that concludes my opening statement, and the gentlewoman from Texas, Eddie Bernice Johnson, is recognized for hers.

Ms. JOHNSON. Thank you very much, Mr. Chairman, and good morning to all. I want to welcome all of our distinguished panel of witnesses, and thank you for your service to the nation. I'd like to welcome our recently appointed new members to the committee and most especially our new Ranking Member, Dr. Bera.

This morning, we will be discussing NASA, whose inspiring mission is nothing short of reaching for the stars. Mr. Chairman, dreaming big is what propels our nation to achieve lasting accomplishments. We all want our children and our grandchildren to believe in dreaming big and yes, in reaching for the stars. NASA provides tangible evidence that we can do just that.

Over the past 6 decades NASA has sent humans to the lunar surface, robotically explored, all the planets in the solar system, landed and operated rovers on Mars, monitored Earth and its systems, and studied the sun, and looked deep into the universe. NASA has led the multination International Space Station partnership and has supported continuous human operations on the International Space Station for over 15 years.

In addition, NASA has made significant progress in demonstrating the use of commercially contracted services for cargo resupply of the ISS. And NASA anticipates that the ISS commercial crew transportation services will begin within the next few years.

NASA continues to follow the priorities of the National Academies' Decadal Surveys for its service program. For example, the James Webb Space Telescope scheduled for launch in October 2018 will enable us to examine the first light after the Big Bang to the formation of galaxies, stars, and planets.

I also want to recognize NASA's Earth science program, which has a long history of space-based observations in support of research to better understand our Earth's systems and our changing climate.

In addition, NASA carries out aeronautics research, which has been vital to the growth and safety of America's aerospace industry. Today, NASA is making steady progress on developing the Space Launch System, the Orion spacecraft, and the exploration ground systems, the key systems that will enable us to once again send our astronauts beyond low-Earth orbit and eventually to Mars.

And as important as these activities are to advancing our priorities in space and aeronautics, they are no less important to us here on Earth. Advances in human health research and medical diagnostic tools, materials, and advanced technologies developed through the space program have all helped improve our daily lives. However, we cannot take NASA's incredible achievements or the benefits they provide for granted. They will not continue without a sustained commitment of vision, resources, and support.

It is clear that the challenge ahead of us is to provide NASA with stability and sustainability so that it can carry out the challenging task that our nation has given it. We can get to Mars, but we need a plan to do so that is sustainable over multiple decades. We can answer the difficult question of whether there is life in the uni-

verse by continuing to support the scientific investigation of our solar system and beyond. I have no doubt that, working together, we can enable NASA to do these things and more. However, we must be careful not to undo NASA's progress by changing directions with every new Administration. Simply put, we must commit to staying the course.

Mr. Chairman, at a time when much of our national discourse revolves around what divides us, we can look to our space program as something that unites us.

Well, we have a lot to discuss this morning and I look forward to our witnesses' testimony. I also look forward to working with you, Mr. Chairman, our colleagues on the Committee, and the new Administration to ensure that we give NASA and its partners the stability, sustainability, and resources needed to continue our leadership in sciences, aeronautics, human spaceflight, and exploration. I thank you and I 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
"NASA: Past, Present, and Future"
 February 16, 2017

Good morning. I want to welcome our distinguished panel of witnesses and thank you for your service to the nation. I would also like to welcome our recently appointed new Members to the Committee. This morning we will be discussing NASA, whose inspiring mission is nothing short of "reaching for the stars".

Mr. Chairman, dreaming big is what propels our Nation to achieve lasting accomplishments. We all want our children and our grandchildren to believe in dreaming big and yes, in reaching for the stars.

NASA provides tangible evidence that we can do just that. Over the past 6 decades NASA has sent humans to the lunar surface, robotically explored all the planets in the solar system, landed and operated rovers on Mars, monitored the Earth and its systems, studied the Sun, and "looked" deep into the Universe. NASA has led the multi-nation International Space Station partnership and has supported continuous human operations on the ISS for over 15 years. In addition, NASA has made significant progress in demonstrating the use of commercially contracted services for cargo resupply of the ISS. And NASA anticipates that ISS commercial crew transportation services will begin within the next few years.

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Thank you and I yield back.

Chairman SMITH. Thank you, Ms. Johnson.

And the gentleman from Texas, Mr. Babin, the Chairman of the Space Subcommittee is recognized for his opening statement.

Mr. BABIN. Thank you, Mr. Chairman. Good morning. I'd like to welcome you all here today for a very important discussion on where NASA has been and where it is and where it will go. I find it difficult to imagine a more qualified panel of witnesses with more personal insight and experience than the one before us today, than Dr. Schmitt, Lieutenant General Stafford, Dr. Stofan, and Mr. Young. I want to thank you very, very much for taking your time to come out from your busy schedules to be with us this morning.

America's civil space program is nearing its 70th anniversary, and in the seven decades since NASA's birth, astronauts have walked on the lunar surface, spacecraft have ventured out into the interstellar void, telescopes have discovered thousands of planets orbiting other stars in our galaxy, but those exciting achievements were not free. It is very difficult to explore a universe of infinite wonder with a finite budget. We must prioritize our visions and destinations in a way that reflects responsible stewardship of American taxpayer dollars.

Fortunately, the election of a new Administration and the start of a new Congress has given us the important opportunity to think about our space program and consider bold new directions and the future for our space program. For instance, should we return to the Moon? How can we ensure that the progress made on deep space exploration capabilities like the Space Launch System and the Orion continues in a fiscally responsible manner? Can public-private partnerships and international collaboration augment taxpayer investment? How would those partnerships be structured to ensure safety and attract private sector contributions and provide value to the taxpayer? Can we both extend ISS operations past 2024 and conduct deep space exploration without significant increases in NASA's budget?

NASA's hard work over many decades is on track to provide the nation with the tools it needs to make a bigger, bolder future in space, and now is the time to start talking about what that future will look like. I hope that our witnesses here today can help make that conversation as lively and as vibrant as possible.

Our continued leadership in space is not just about exploration. Our national security, our international standing, and economic competitiveness all depend on our leadership in space.

I couldn't be more excited to discuss these crucial questions with today's witnesses, and I want to thank you all again for being here and I look forward to your testimony.

I will yield back, Mr. Chairman.

[The prepared statement of Mr. Babin follows:]



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

For Immediate Release
 February 16, 2017

Media Contact: Kristina Baum
 (202) 225-6371

Statement of Space Subcommittee Chairman Brian Babin (R-Texas)
NASA: Past, Present, and Future

Chairman Babin: Thank you, Mr. Chairman. Good morning. I'd like to welcome you all here today for an important discussion on where NASA has been, where it is, and where it might go. I find it difficult to imagine a more qualified panel of witnesses with more personal insight and experience than the one before us today. Thank you all very much for taking time out of your busy schedules to be with us.

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I couldn't be more excited to discuss these crucial questions with today's witnesses. Thank you all, again, for being here. I look forward to your testimony.

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Chairman SMITH. Thank you, Mr. Babin.

And the gentleman from California, Mr. Bera, the Ranking Member of the Space Subcommittee, is recognized for an opening statement.

Mr. BERA. Thank you, Mr. Chairman. And good morning and welcome to the distinguished panel.

Listening to the Chairman's description of the panel makes all of us feel like underachievers here.

I also want to just take a moment to thank my Democratic colleagues for selecting me as the Ranking Member on the Space Subcommittee for this Congress.

As a kid who grew up in Southern California in Downey, home of Rockwell International, much as my generation, the space program epitomized the national pride that we had in America, the fact that President Kennedy challenged us to dream beyond what we knew we could do, yet we set our minds to it, we focused on it, we recruited the best talents, and we went out and achieved it. And getting back to that pride is incredibly important.

I think all of us remember waking up early in the morning to watch Apollo launches, holding our breath, watching Apollo-Soyuz, Skylab, the Space Shuttle, and we've got to recapture that imagination again. We've got to—as the Ranking Member said, we've got to dream big. And that's why SLS and Orion are so important.

We don't know yet how we're going to go to Mars with human space travel and return, but the goal of imagination and dreaming and achievement isn't doing what you know how to do, it's about setting that goal, taking the talent that we have in America, and putting our minds to it. Yes, we have limited resources, yes, we have other priorities, but we've got to get back to dreaming big.

And it is that vigor that inspired a generation of kids to go into the sciences to move forward, and if we want to continue that superiority in technology and American pride, the importance of our national defense, it was great to see Dr. Stofan's opening remarks from my home State of California some of the work that NASA is doing in helping us manage water and address it—and it seems funny to be talking about a drought right now in this really wet winter, but what NASA does in helping us manage weather forecasting and so forth, it's incredibly important and national security.

So, I am deeply honored to be the Ranking Member. The members of this Committee do not—this is not a Republican or a Democratic issue. This is about national pride and leading the way. And I don't want an American space program that follows. I want an American space program that moves us forward and leads and works with the international community to continue to go to that next frontier.

In my own District we've got an Aerojet Rocketdyne facility, and when I visit the workers out there and when I listen to the President talk about bringing manufacturing jobs back to America, it's those types of jobs that are not the jobs of the last century but the jobs of the next century. And it is pretty amazing the work that they're doing. And if we make the right investments, we can lead the way once again and lead the 21st century space program.

So, thank you to the distinguished panel. Thank you to the Chairman for calling this hearing, and I look forward to working in the 115th Congress to make this a reality.

[The prepared statement of Mr. Bera follows:]

OPENING STATEMENT
Ranking Member Ami Bera (D-CA)
of the Subcommittee on Space

House Committee on Science, Space, and Technology
"NASA: Past, Present, and Future"
February 16, 2017

Good morning. And welcome to our distinguished panel.

Thank you Mr. Chairman for calling this hearing. I also want to thank my Democratic colleagues for choosing me to serve as the Ranking Member for the Subcommittee on Space this Congress.

NASA remains a critical national asset. For nearly 60 years, it has been a source of technological and scientific innovation, an inspiration to generations of Americans, and a catalyst for economic growth.

It is also a symbol of American excellence and a demonstration of our commitment to international cooperation in the peaceful uses of outer space. The International Space Station is a shining example of when countries can come together to achieve great things.

An issue I am passionate about is finding ways to resolve water shortages that impact the livelihood of many Sacramento County families, farmers, and small businesses that I represent in the 7th District of California. That is why I was heartened to read, in Dr. Stofan's prepared statement, of the positive impact made by NASA satellites in providing critical information such as soil moisture and groundwater depletion. Her description of a NASA-developed system that processes satellite data to track field-by-field water use, currently utilized by fifteen states including California to help water managers balance their water resources, is a clear reminder that NASA's contributions also benefit people here on Earth.

It is fitting that this hearing will provide an opportunity to remind us of just how much NASA has accomplished in the past six decades, and hopefully, it will also provide additional motivation for my colleagues to support NASA in achieving greater things in the decades ahead. The landing on the Moon by Neil Armstrong, images of distant galaxies by the Hubble Space Telescope, construction of the Space Shuttle in my home state of California, and rover exploration of the Red Planet—all these amazing feats are well known to generations of young Americans.

The future of NASA looks just as bright. Soon, the OSIRIS-Rex spacecraft will reach the asteroid Bennu and attempt to return a sample back to Earth for analysis; the Space Launch System and Orion will fly as an integrated system, an important step as our astronauts prepare once again to explore beyond low Earth orbit; the James Webb Space Telescope will use infrared

light to examine every phase of cosmic history; and the Surface Water Ocean Topography mission will monitor water level changes in our rivers and reservoirs, improving our weather and climate models in addition to forecasting flood and drought situations.

For NASA to do these great things, including preparation for landing humans on Mars, it is critical that Congress continue to invest in NASA and provide it with the long-term stability it needs and deserves.

I hope today's hearing will emphasize that message.

Thank you Mr. Chairman and I yield back.

Chairman SMITH. Thank you, Mr. Bera.

Our first witness today is Hon. Harrison Schmitt, an Apollo 17 astronaut and former U.S. Senator from New Mexico. His career as a geologist has taken him around the world and beyond. In 1965 he was selected as a NASA scientist astronaut. In 1971 Dr. Schmitt was assigned as a lunar module pilot for the Apollo 17 mission. He is the first and only scientist to walk on another celestial body. He then went on to serve in the U.S. Senate for six years, and he has also served as Chairman of the NASA Advisory Committee.

With the sad passing of Gene Cernan, Dr. Schmitt is the last person alive to walk on the Moon.

Dr. Schmitt has a bachelor's of science from the California Institute of Technology and his doctorate in geology from Harvard University.

I'll now recognize the Vice Chairman of the Science Committee, the gentleman from Oklahoma, Mr. Lucas, to introduce our next witness.

Mr. LUCAS. Thank you, Mr. Chairman. And it is my privilege to introduce Lieutenant General Tom Stafford. Lieutenant General Stafford was born and grew up in Weatherford, Oklahoma, a town in my district literally just down the road from my hometown of Cheyenne. He was selected to be a part of the second astronaut class as a member of the Air Force in 1962 where he began an amazing career. He commanded Gemini VI and Gemini IX before heading the mission planning analysis responsibilities for the Apollo project. And as commander of Apollo 10, he performed the first flight of the lunar module 9 miles above the lunar surface and designated the first lunar landing site, obviously good radar and photography there, General, as successful as that was.

Following the Apollo program, he worked at the NASA manned spaceflight center and logged his fourth spaceflight as an Apollo commander of Apollo-Soyuz test project mission in 1975, which helped end the space race.

Since coming back to Earth, Lieutenant General Stafford worked as the Deputy Chief of Staff for the acquisitions at the Air Force. He initiated the F-117A stealth fighter, wrote the original specifications for the B-2 stealth bomber. He served as an advisor to the NASA Administrators over the past 20-plus years and has personally helped various vice presidents assess NASA's capacities and objectives. And he's currently Chairman of NASA's Advisory Council Task Force for the International Space Station safety and operational readiness.

Lieutenant General Stafford, I believe I can speak on behalf of the whole committee and certainly every one of our fellow Oklahomans, we are honored that you are with us today and this morning and we look very forward to your comments. And as always, thank you for your service. I yield back, Mr. Chairman.

Chairman SMITH. Thank you, Mr. Lucas.

Our next witness, Dr. Ellen Stofan, served as NASA's Chief Scientist from 2013 to 2016. There, she served as Principal Advisor to the NASA Administrator on the agency's science-related strategic planning and programs. As a scientist, her research has focused on the geology of Venus, Mars, Saturn's moon Titan, and the Earth. Dr. Stofan holds a bachelor's degree from the College of William

and Mary and a master's and doctorate degree in geological sciences from Brown University.

Our last witness today is Mr. Tom Young, and he is the former Director of NASA's Goddard Space Flight Center, the former President and COO of Martin Marietta, and former Chairman of the Science Applications International Corporation. He began his career with NASA at the Langley Research Center in 1961 and became Director of the Planetary Program at NASA headquarters in 1967. Mr. Young was recognized with NASA's highest award, the Distinguished Services Medal, for his role in the Viking project, the first time any country has successfully landed a payload on Mars.

Mr. Young earned both a bachelor's degree in aeronautical engineering and a bachelor's degree in mechanical engineering from the University of Virginia and a master's of management degree from MIT.

We welcome you all and certainly recognize your collective expertise. And, Dr. Schmitt, we'll begin with you.

**TESTIMONY OF HON. HARRISON SCHMITT,
APOLLO 17 ASTRONAUT,
FORMER UNITED STATES SENATOR**

Dr. SCHMITT. Thank you, Mr. Chairman.

I am an explorer. Freedom in America uniquely enhances the human drive to explore beyond familiar and/or unknown boundaries. Exploration is in our blood, as has been indicated by your statements. From the founders' foray into constitutional government to entrepreneurial enhancement of our pursuit of happiness to Jefferson and Lewis and Clark's opening of the American West and yes, to Eisenhower and Kennedy's bold initiatives leading to Armstrong's first small step on the Moon.

Now, the Moon and Mars and deep space beckon new generations of young Americans, and I emphasize young. We would ignore their call at our peril.

A program for Americans to land on Mars would be a remarkable and historic answer to that call. Such a landing, however, will not be easy. Mars has just enough atmosphere to cause trouble on entry but not enough to help. The great distance between Earth and Mars mean crews will not have mission control to help in critical operations. Gravity on Mars may or may not help astronauts adapt physiologically. Long transits to Mars may require artificial gravity and/or fusion propulsion and definitely will require heavy shields of water for radiation protection. The capability to launch 100 metric tons to Earth escape velocity may be required. At least two generations of young engineers, scientists, and skilled workers must relearn how to deal with the challenges and risks of deep space.

To meet these challenges I am convinced that the Moon is a necessary steppingstone with great geopolitical and scientific value in its own right. Only 3 days away rather than many months, the Moon provides necessary resources, engineering verification, operational training, physiological insights, private sector partnerships, and the immediate geopolitical high ground.

If the United States returns to deep space, Congress can gain valuable lessons from the Apollo Cold War space effort. The keys

to success for the Apollo program were a sufficient base of technology and aircraft and spaceflight experience to begin; a large reservoir of patriotic young Americans and skilled workers, the Sputnik generation; a pervasive environment of national unease; the catalytic events of Sputnik and Yuri Gagarin's orbital flight; an articulate, persuasive, and patriotic President and Congress; a Congressional and White House commitment to about 100 percent manager reserve of funding so schedule could be maintained in the face of unknown and unknown-unknown problems; tough, competent, disciplined, courageous managers; and possibly as important as anything, a working environment of liberty.

All these keys must accompany a Moon/Mars/deep space initiative but also include in addition today improved education in STEM skills and critical thinking, substitution of China's ambitions for the Cold War stimulus of the 1960s, a permanent national commitment to deep space exploration, maintenance of an average workforce age of less than 30 years, and elimination of an aversion to taking necessary risk.

As detailed in my submitted testimony and on the America's Uncommon Sense website, a focused Apollo-style management system will be needed. This system must stay young, stay lean, and stay risk-takers. Once the decision to go back to the Moon and on to Mars is made, the sole focus of civil space management should be to do just that.

With a well-managed Moon/Mars/deep space program, having sustained annual funding levels of about \$20 billion per year, including 30 percent management reserve, the following milestones should be possible: return Americans to the Moon service by 2025, lunar settlement by 2030 with public and private capital funding partnership, lunar resource production by 2035 with private capital funding and management primarily, fusion-powered interplanetary booster also by 2035, Mars crew landing by 2040, and I believe Mars settlement by 2045. That's a big agenda.

In conclusion, returning to the Moon will increase significantly the probability of success of a Mars landing and exploration program and to maximizing its scientific returns. Because of the multidecadal nature of such an effort, such a return to deep space exploration requires the unequivocal and sustained commitment of the nation, even more so than was required for the Apollo program again because of its multidecadal aspects.

Finally, if the decision is to move quickly to reassert American dominance in space, we are, I believe, well-positioned to do so. The geopolitical environment facing freedom today is as critical as that which faced Congress and the Eisenhower and Kennedy Administrations prior to Apollo. Our current technological foundations actually greatly exceed those of May 1961 having been vastly expanded by the nation's public and private sectors.

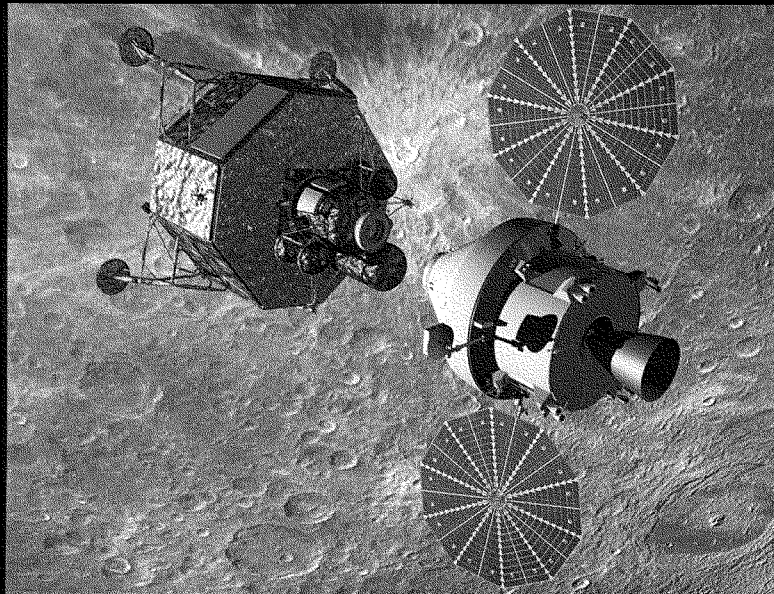
Development of the Space Launch System is well ahead of Saturn V development at a comparable time thanks to leaders in Congress such as yourselves and to leaders in NASA. The Orion spacecraft is in test rather than being just a sketch on a blackboard. Constellation's Altair lunar lander design progressed well beyond early concepts of the Apollo lunar module. Understanding of human physiology and space has been greatly advanced by use of

Skylab, the shuttle, and the ISS. Unlike the 1960s, the private sector is well-positioned to support as well as to partner with the federal government.

I believe, Mr. Chairman, Congress and the Administration should move America back into deep space sooner rather than later. Thank you for your attention. I look forward to comments of my colleagues, and I would be happy to answer any questions that you or the committee may have. Thank you.

[The prepared statement of Mr. Schmitt follows:]

**The Moon is on the Path to get to
Mars and Beyond**



**Honorable Senator Harrison H. Schmitt, Ph.D.,
Apollo 17 Lunar Module Pilot**

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

February 16, 2017

*Honorable Senator Harrison H. Schmitt, Ph.D.,
Apollo 17 Lunar Module Pilot*

Cover Caption:

An *Altair* Lunar Lander (*left*) is seen separating from an *Orion* Crew Module (*right*) in lunar orbit. *Orion*, which was originally part of the *Constellation* program, is currently being developed with some modifications as the *Orion* Multi-Purpose Crew Vehicle (MPCV) and is now undergoing tests. A fully-crewed MPCV is planned for a lunar free return (non-landing) mission by 2021; but it could easily be adapted with a completed *Altair* vehicle for landings on the Moon. (Lockheed Martin photo)

The Moon is on the Path to get to Mars and Beyond*

**Honorable Senator Harrison H. Schmitt, Ph.D.,
Apollo 17 Lunar Module Pilot**

Introduction

If the President proposes a major new initiative in the human exploration of deep space to Congress, such as a return to the Moon as a cornerstone of missions to Mars and beyond, Congress and the Administration should evaluate the successful implementation of a comparable space effort, namely Apollo. The keys to the success of the Apollo Program (**Fig.1**) included the existence of:

- A sufficient base of technology,
- A large reservoir of patriotic young engineers and skilled workers,
- A pervasive environment of national unease,
- The catalytic event of Yuri Gagarin's orbital flight,
- An articulate, persuasive and patriotic President and Congress,
- A commitment of a ~100% management reserve of funding, [1]
- Tough, competent, disciplined and courageous managers, [2]
- A goal that could be accomplished in a decade, and
- A working environment of liberty.

All these keys to success must accompany a Moon-Mars-Deep Space Program with the following additions:

- A permanent national commitment to deep space exploration,
- China's rapid progress substitutes for the original Cold War stimulus for Apollo,
- Improved education in Science, Technology, Engineering, and Math (STEM) skills, and critical thinking,
- Maintenance of an average workforce age of <30 years. Given the advance of technology, a ~30% management reserve through systems' Critical Design Reviews (CDRs) may be adequate, and
- Elimination of the political aversion to taking necessary risks.

* Condensed from the 56th article and 8th in a series on Space Policy archived on the AUS website (<http://americasuncommonsense.com>).

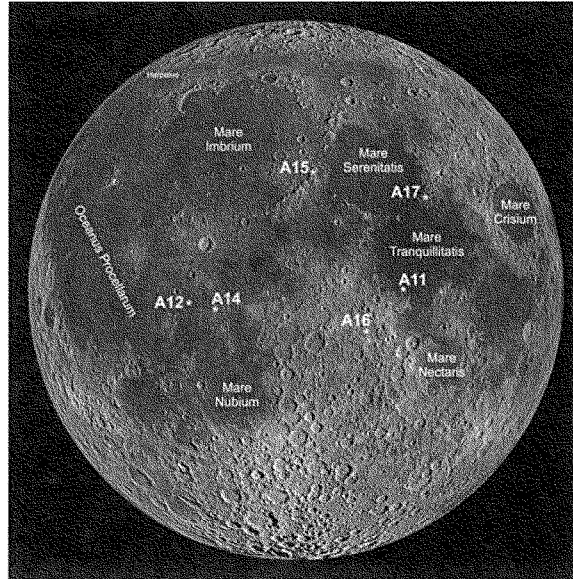


Fig. 1. The six landing sites of Apollos 11, 12, 14, 15, 16 and 17. Apollo 17, the last mission, landed on the eastern shore of Mare Serenitatis in the Valley of Taurus-Littrow on Dec. 11, 1972. (Base map, NASA/ASU/GSFC photomosaic from the Lunar Reconnaissance Orbiter Wide Angle Camera).

Major Mars Requirements

The catalysts for initiating a Mars Program exist today and include all of the following: geopolitical reality with respect to China and Russia; economic need to stimulate future technologies; and addressing the crisis in engineering and science education, and education in general, facing the United States. Also, deep space operational experience must be regained by continuous generations of young implementers. Finally, and most importantly, there must be a permanent public and political commitment to deep space exploration and development on a par with, and related to a commitment to National Security.

A focused Apollo-style management system will be needed. This system must “stay young—stay lean—stay risk takers.” Once the decision to go back to the Moon and on to Mars is made, the sole focus should be to do just that. With such a decision, early tradeoff studies will be needed on interplanetary propulsion development, consumables requirements and sources, specialized technology development, and human spaceflight planning and operations. Additionally, the first landing mission to Mars will drive decisions on development and operations, specifically, crew size and capabilities (one or two crews with one or two landers), desired exploration science returns, space resources delineation and use, and the role of private investment in an integrated program.

Management Requirements

The success of Apollo depended on the rapid evolution of a management system that, with hindsight, includes many common sense attributes. NASA and its contracting corporations had access to the best engineers and engineering managers available, inherited from the National Advisory Committee on Aeronautics (NACA), the Army Ballistic Missile Agency and Corps of Engineers, assignees from the three military services, the Canadian Avro Corporation, and engineering schools from around the country.

Because of the short, roughly 11-year duration of the Apollo Program (**Fig. 2**), the average age of the NASA and contractor workforce remained below 30 years. Congress should note that this workforce characteristic has been maintained over many decades by an equally complex nuclear Navy with continued success as well as in many other aspects of our national defense establishment. Youth provides the motivation, stamina, patriotism, courage and sense of liberty to see projects to successful conclusions.

The bureaucratic newness of NASA in the 1960s also meant that management was minimally layered so that decisions could be made quickly and good ideas could move rapidly to implementation (Note: Between November 1968 and November 1969, a Saturn launch and Apollo space mission took place every 2 months.). NASA also supported an internal, independent engineering design capability that gave managers alternative viewpoints to those of contractors on major issues. Finally, Administrator James Webb persuaded the White House and Congress to provide a management funding reserve sufficiently great to maintain schedule in the face of unexpected engineering issues and accidents.



Fig. 2. The author walking past the south side of a large split boulder at Station 6 visited by the Apollo 17 astronauts on Day 2 after the landing, driving there with the Lunar Rover seen at right. The Lunar Module itself is ca. 3.5 km distant in the whitish area just right of the tip of the boulder. (Composite of NASA photos AS17-140-21495, -96 and -97)

These management lessons and requirements should be embedded in the enabling legislation for a Moon-Mars-Deep Space Program, in particular:

- Congress should explicitly define the management responsibility for the program and charge that management solely with the human exploration of deep space and the re-establishment and maintenance of American dominance as a space-faring nation.
- Congress should give the implementing agency the personnel authority to hire, fire and re-assign employees as necessary to maintain the youth and vigor of the program.
- Congress should insure that adequate funding reserves are budgeted to account for development unknowns that otherwise would impact scheduled milestones.
- Congress should commit, as best it can, to an annual, inflation-adjusted funding level for the Moon-Mars-Deep Space Program that would insure the achievement of specific milestones as well as a permanent geopolitical commitment to deep space exploration.
- Existing NASA Centers and/or elements of Centers with a heritage of developing and operating human spaceflight systems and exploration precursors should come under the direct authority of this implementing agency.
- Lunar and planetary science and resource identification should be identified as a major component of human space exploration and development initiatives [3].
- A full managerial and budgetary separation should be made of space activities not directly associated with the Moon-Mars-Deep Space Program with consideration given to the re-establishment of the National Advisory Committee on Aeronautics and the relocation of non-exploration related space science projects to relevant agencies.
- With appropriate recognition of our international responsibilities, the International Space Station (ISS) should be utilized for scientifically established protocols to identify as statistically as feasible the adverse physiological consequences and risks of long duration exposure to micro-gravity and to evaluate appropriate counter-measures to those consequences.

Moon in the Context of Mars

Consideration of missions to Mars should include the value of returning to the Moon as a means of dealing with many of the challenges Mars presents (**Fig. 2**). The Moon lies only three days away in regard to Mars mission development, simulation and training versus the many months required to reach Mars. Flying to the Moon and working there require similar deep space operational discipline that new generations of space managers, engineers and flight controllers will need to assimilate. Also, many of the same deep space technological capabilities will be needed.

The Moon remains geopolitically critical in its own right. The existence of space consumable resources and potential energy sources [4] of importance to Earth have not been lost on other international players. Accessing and developing these resources presents the possibility of cost reduction through private-government partnerships. Further, evaluation of the effects of 1/6 Earth's gravity on physiological re-adaptation will answer the question, for better or worse, concerning the consequences of re-adaptation requirements in the 3/8 Earth's gravity of Mars.

Important new and unique science will come from a return to the Moon. Whereas Mars will give new insights into pre-biotic and, potentially, early biotic history, the Moon provides a record of the extraordinarily violent impact history in which life's precursors formed. [5]

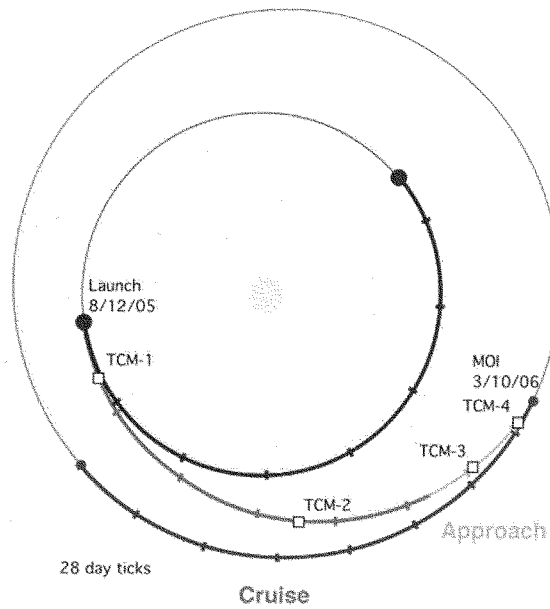


Fig. 3. A typical Mars transit trajectory, in this case followed by the Mars Reconnaissance Orbiter spacecraft launched on Aug. 12, 2005 and still operating as of this date. The green line is a minimum energy “Hohmann” transfer orbit between the inner Earth and the outer Mars orbits. Depending on launch times, Hohmann transfers can take 7-8 months one-way. (NASA photo)

Mars Transit Hurdles

Missions to Mars (**Fig. 3**) will not be easy for many years to come, if ever. Transit alone presents the issues of radiation protection, micro-gravity countermeasures, consumables supplies, spacecraft redundancy and maintenance, crew proficiency for landing and

return, crew composition and crew compatibility, and challenging in-flight work. Solutions to some of these issues may relate to solutions to others; however, many potential solutions require consideration of a return to the Moon to stay.

Water, oxygen, nitrogen, hydrogen, methane and other consumables provided by lunar resources can significantly reduce the required Earth launch mass of Mars-bound spacecraft. Among those other potential consumables is helium-3, a potential fuel for fusion-powered propulsion that could shorten transit time considerably. Crew suitability and compatibility for long duration missions can be evaluated with an extended stay at the International Space Station (ISS), followed by an exploration mission on the Moon, and then by another extended stay at the ISS.

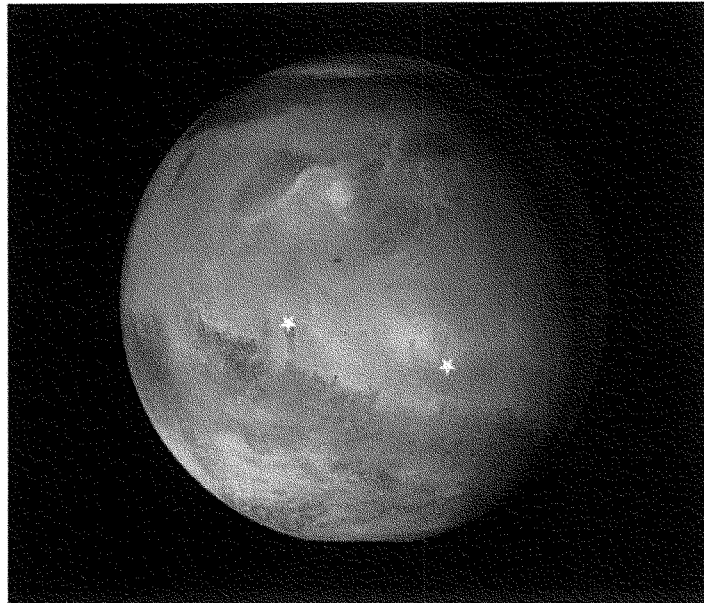


Fig. 4. A global composite of photos taken by the Mars Global Surveyor orbiting spacecraft. The two stars mark the landing sites of the Spirit and Curiosity Rovers in Gusev Crater (right), southeast of Elysium Planitia; and in Gale Crater (left), due South of Elysium, respectively. The circular white area above the center is probably surface frost on the Elysium volcano as it is early northern Spring, or possibly a summit cloud. (Base photo from NASA/JPL/Malin Space Science Systems photo, PIA08019)

Mars Landing Hurdles [6]

Mars has enough atmosphere (~1/200th of Earth's) to cause entry, descent and landing (EDL) problems, but not enough to help much in kinetic energy dissipation. It is generally calculated that a Mars Lander will have an initial mass of at least 40 metric

tonnes as compared to the 4 metric tonnes of Curiosity (**Fig. 4**). This is not a trivial issue. Further, EDL must be accomplished without real-time assistance from Mission Control. Landing, whether automated or not, likely will utilize a beacon operating from a previously landed, un-crewed habitat-supply precursor necessitating a rover-assisted, surface rendezvous after landing. It also is likely that *in situ*, return fuel production will need to be demonstrated prior to Earth-launch of the paired crewed mission.

Whatever approaches to EDL ultimately are developed for operational testing, such tests probably will take place at appropriate altitudes in the Earth's atmosphere and during simulated Mars landing profiles near the Moon. Also, operational technologies and procedures will need to be developed to support consideration of aborts to a landing in contrast to aborts to orbit. Future lunar landings offer the best means of testing abort-to-land concepts along with doing so with simulated Mars communications constraints.

Related to abort-to-land considerations will be evaluation of whether each early Mars mission should consist of two landers and two full crews. The cost, time and risk inherent in Mars missions argue for steps to maximize landing and exploration success. In the likely event that both landers reach the surface successfully, the science return from two separate landing sites will be an added benefit to adopting this approach. (If only one landing is successful, the second prepositioned un-crewed lander will be available for a later mission.) An additional potential benefit of having two crews is that the orbiting crew can provide real-time mission support during landing and ascent and during other nominal or off nominal events. This latter activity compensates, in part, for the absence of real-time Mission Control input.

An additional point relative to landers, as well as Earth-entry modules, is that they should also have the simulation capability for proficiency training during Mars transit.

Major Mars Exploration Hurdles

Exploration of the surface of Mars will have many similarities to future lunar exploration. Lunar preparatory missions provide the means of testing, operating and maintaining Mars-consistent equipment such as mixed-mode rovers, sampling and analytical tools, analytical equipment for return sample selection, bio-containment systems for drills and sample packaging, dust mitigation concepts, food production concepts, and nuclear power systems.

Of particular importance will be the evaluation of Mars extravehicular mobility units (EMU). Whereas, Apollo EMUs were designed for use over just a few days, Mars EMUs will need to be designed for long duration use and maintenance. Lunar exploration provides an unique opportunity for testing such systems over extended cycles of use in a realistic environment.

Simulation of a variety of operational issues that will arise during Mars exploration can be conducted on the Moon. These include variable communication delays that can be integrated into lunar exploration, providing real-world operational experience with this

form of crew-Earth interaction. If assistance from an orbiting crew becomes part of Mars landing and exploration, this concept can be evaluated and refined as well. Also, forward and back contamination protocols can be evaluated for feasibility and efficacy. Further, methods for Mars exploration data synthesis, archiving and near real-time retrieval can be developed and evaluated in the context of actual lunar exploration activities.

Although consumables production (water, oxygen, nitrogen, helium, fuels and food) on the Moon begins with processing regolith rather than the potentially more chemically challenging Mars surface materials, the operational experience with such processing, as well as volatiles refining, will provide invaluable experience in the design of consumables production systems for Mars.

Mars Physiological Issues

It is currently unknown if the 3/8 Earth's gravity of Mars will trigger gravitational re-adaptation in landing crews and, if so, how much crew time will such re-adaptation require. The integration of a research protocol into future lunar exploration to determine whether 1/6 Earth's gravity triggers re-adaptation will serve two purposes. If lunar gravity triggers re-adaptation, there will be less complexity in engineering design and operational planning. If this does not happen, then design, planning and development of countermeasures become more complex, but this complexity can be taken into account earlier than otherwise would be possible.

Potential Mars Program Milestones

It is estimated that with a well managed Moon–Mars–Deep Space Program, having a sustained annual public funding level of about \$20 billion per year (2017 dollars), including a 30% management reserve, the following major milestones could be achieved:

- Return to the Moon's Surface by 2025.
- Lunar Settlement by 2030 (Public / Private Capital Funding).
- Lunar Resource Production by 2035 (Private Capital Funding and Management).
- Fusion-powered interplanetary booster by 2035 (Public / Private Capital Funding).
- Mars Landing by 2040.
- Mars settlement by 2045.

An essential ingredient to achieving these milestones is the existence of a space launch system capable of accelerating ~100 metric tonnes to escape velocity. Upgrading and fast-tracking the current Space Launch Systems (SLS) to match these capabilities are required objectives in this regard.

Conclusion

A return to the Moon appears to be essential to increasing significantly the probability of success of a Mars landing and exploration program and to maximizing the scientific return from such a program. Such a return to deep space exploration, however, requires the unequivocal and sustained commitment of the Nation, even more so than was required for the Apollo Program because of the multi-decadal nature of the effort.

Mars also provides a geological integration of the early solar system impacts recorded by the Moon and the contemporaneous water-rich, pre-biotic period on Earth. Mars exploration has the potential to unravel the origin of life on Earth, as well as being a geopolitical imperative for democratic nations.

Finally, if a decision is made to move quickly to re-assert United States dominance in space, we are well positioned to do so. The geopolitical environment facing the United States today is as critical as that which faced the Congress and the Eisenhower and Kennedy Administrations prior to Apollo. The technical capabilities available actually significantly exceed those of May 1961. Thanks to leaders in the Congress and NASA, the development of the Space Launch System is well ahead of Saturn V development at a comparable time. The Orion spacecraft is in test rather than just being on the drawing board. Constellation's Altair Lander design has progressed well beyond that of the early Lunar Module designs. Unlike the 1960s, the private sector is well positioned to support as well as partner with the government. It is time to move forward sooner rather than later.

References

- [1] Lambright, W. H. and Webb, J. E. (1995) *Powering Apollo*, Johns Hopkins, 101.
- [2] Kranz, E. (2000) *Failure is Not an Option*, Simon & Schuster, 119-384.
- [3] Schmitt, H. H. (2012) *Space Policy and the Constitution*, America's Uncommon Sense website, <http://www.americasuncommonsense.com/blog/>, Downloads: Space Policy and the Constitution (PDF link, or PRC Kindle link).
- [4] Schmitt, H. H. (2006) *Return to the Moon*, Springer, 335p.
- [5] Schmitt, H. H. (2015) *GSA Spl. Paper 518*, 1-16.
- [6] Braun, R. D. and Manning, R. M. (2007) *Spacecraft & Rockets*, 310-323.

Harrison H. Schmitt is a former United States Senator from New Mexico as well as a geologist and Apollo 17 Astronaut. Dr. Schmitt is currently an aerospace and private enterprise consultant. Dr. Ronald Wells assisted in the final preparation of this manuscript.

HONORABLE HARRISON HAGAN SCHMITT
NASA APOLLO 17 ASTRONAUT
U. S. SENATOR (R-NM) (FORMER)

PERSONAL DATA: Harrison Hagan Schmitt was born July 3, 1935, in Santa Rita, New Mexico and grew up in the nearby community of Silver City, New Mexico. He currently resides in the Intermountain West and works as a consultant in aerospace and earth and planetary science.

EDUCATION: Graduated from Western High School, Silver City, New Mexico in 1953; received a bachelor of science degree in science from the California Institute of Technology in 1957; studied as a Fulbright Fellow at the University of Oslo in Norway from 1957 to 1958; received a doctorate in geology from Harvard University in 1964 based on geological work in western Norway; and was a National Science Foundation Post-Doctoral Fellow in 1963-1964. Schmitt received his Air Force jet pilot wings in 1966 and Navy helicopter wings in 1967. In addition to his Doctorate of Philosophy in Geology from Harvard University, Dr. Schmitt has been privileged to receive honorary doctorate degrees from Rensselaer Polytechnic Institute, University of New Brunswick, Colorado School of Mines, University of New Mexico, New Mexico State University, University of Alabama-Huntsville, Salem College, Franklin and Marshall College, and South Dakota Institute of Technology.

EXPERIENCE: Schmitt began his geological career as a field assistant to his father, noted economic geologist Dr. Harrison Ashley Schmitt, followed by extensive instruction at Caltech by several of the top field geologists in the world. He also worked for two summers as an exploration geologist investigating the ultramafic rocks of Duke Island in southeastern Alaska (1955 and 1956). He was a teaching fellow at Harvard in 1961 under Professor Hugh McKinstry during which time he assisted in teaching a course in the geology and economics of precious metal deposits. In 1957, he did geological work on the west coast of Norway, returning in 1960 to work in that region for the Norwegian Geological Survey. He also worked in the field for the U.S. Geological Survey in 1953 and 1959 in New Mexico (surveying) and Montana (mapping of the Butte Batholith). Before joining NASA, he was with the U.S. Geological Survey's Astrogeology Center at Flagstaff, Arizona in 1964-1965. At that time, he was project chief for Lunar Field Geological Methods, participated in photographic and telescopic mapping of the Moon and was among USGS astrogeologists instructing NASA Apollo astronauts during their initial geological familiarization field trips. During this period, Schmitt mapped the geology of the Buell Park kimberlite pipe in northeastern Arizona.

Dr. Schmitt was selected as a NASA scientist-astronaut in June 1965, as a member of the 4th group of Apollo astronauts. He then completed a 53-week course in jet aircraft training at Williams Air Force Base, Arizona and a two-week course in helicopter flying at the Pensacola Naval Air Station, Florida. He has logged more than 2,100 hours flying time including 1,600 hours in jet aircraft (primarily T-38 Talons) and 210 hours in helicopters (H-13s).

In addition to training for future manned space flights, Schmitt was instrumental in providing Apollo flight crews with detailed instruction in lunar navigation, geology, and feature recognition. Schmitt assisted in the integration of scientific activities and equipment into the Apollo lunar missions, including the design and deployment of the Apollo Lunar Surface Experiments Packages. Deeply involved in the lunar orbit and surface operations planning for Apollo missions 8-13, he functioned specifically as the Mission Scientist in support of Apollo 11 in 1969. Schmitt also designed and oversaw the implementation of the geological training program for Apollo missions 13-17. Early in 1970, he was assigned as the backup Lunar Module Pilot for Apollo 15 that flew to the Moon in July 1971.

In August 1971, Dr. Schmitt was assigned as Lunar Module Pilot for the Apollo 17 mission, the last manned Apollo mission to the Moon. Apollo 17 launched at 11:33 p.m. (CST), December 6, 1972, and concluded on December 19, 1972. At 301 hours and 51 minutes, the voyage of the Command Module "America", piloted by Ronald Evans, and the Lunar Module "Challenger" constituted the longest manned lunar landing flight. After maneuvering "Challenger" to a landing in the valley of Taurus-Littrow, located on the southeast edge of Mare Serenitatis, the Apollo 17 crew activated a base of operations facilitating their completion of 3 days of geological and geophysical exploration. On the first day of his exploration activities, Schmitt deployed and activated the fifth and last Apollo Lunar Surface Experiments Package.

Schmitt is the first scientist and twelfth and last person to step on the Moon. This last Apollo mission to the Moon for the United States broke several other records, including: longest lunar surface extravehicular activities (22 hours, 4 minutes); longest distance traveled in the Lunar Roving Vehicle (35 km); largest lunar sample return (an estimated 115 kg or 249 lb); and longest time in lunar orbit (147 hours, 48 minutes). Apollo 17 ended with a splashdown in the Pacific Ocean approximately 0.4 miles from the target point and 4.3 miles from the prime recovery ship, USS TICONDEROGA.

Dr. Schmitt remains the only professional geologist and scientist to explore the Moon. Through 44 years of research on the Apollo 17 samples, photographs and observations, Schmitt and hundreds of investigators throughout the world have helped to uncover much of the geological history of the Taurus-Littrow area and its relationships to the early history to the Earth. These findings include further definition of the violent impact history of the Earth during the period when life began; the potential role of the largest impact basin in the evolution of the Moon; identification of samples of the lunar mantle; the definition of the sequence of formation of three large lunar basins; identification of a large igneous body ejected from a basin about a 1000 km distant; the crystallization history and thickness of titanium-rich basalt lavas; the sources and detailed nature of volcanic ash deposits and their implications to understanding the origin of the Moon; the structure and dynamics of young lunar thrust faults; the dynamics and origin of a young lunar debris avalanche; details of lunar regolith formation; and identification of potential samples to help define the history of the lunar magnetic field.

During 1973, Dr. Schmitt and the Apollo 17 crew toured the United States and many

parts of the world, sharing their experiences with thousands. In February 1973, Schmitt assumed additional duties as Chief of Scientist-Astronauts, assisting in the definition of crew responsibilities for space operations during future Space Shuttle missions. In July of 1973, Dr. Schmitt was appointed as one of the first Sherman Fairchild Distinguished Scholars at the California Institute of Technology. His appointment was extended to run through July 1975. This appointment ran concurrently with his other activities at NASA.

Dr. Schmitt was appointed NASA Assistant Administrator for Energy Programs in January 1974. This office had the responsibility for coordinating NASA support to other Federal Agencies conducting energy research and development and for managing NASA programs applying aeronautics and space technology to the generation, transmission, storage, conservation, utilization and management of energy for terrestrial applications.

In 1975, after 2 years managing NASA's Energy Program Office, Schmitt fulfilled a long-standing personal commitment to public service by entering politics. Elected in 1976, he served a 6-year term in the United States Senate beginning in 1977. Senator Schmitt, the only "natural scientist" in the Senate since Thomas Jefferson was Vice-President of the United States and President of the Senate. Senator Schmitt worked as a member of the Senate Commerce, Banking, Appropriations, and Intelligence Committees, and as Vice-Chairman of the Senate Ethics Committee. In his last 2 years in the Senate, Schmitt held the position of chairman of the Commerce Subcommittee on Science, Technology, and Space and of the Appropriations Subcommittee on Labor, Health and Human Services, and Education. He was active legislatively on policy issues related to strategic defense, military air transport, intelligence, immigration, energy, communications, space and science, patents, ethics, and the Panama Canal Treaty.

After leaving the Senate, Schmitt served on the President Ronald Regan's Foreign Intelligence Advisory Board, the President George H. W. Bush's Commission on Ethics Law Reform, the Army Science Board, Advisory Board of the Smithsonian Air and Space Museum, as co-chairman of the International Observer Group for the 1992 Romanian elections, and as vice chairman of the U.S. delegation to the 1992 World Administrative Radio Conference in Spain. Schmitt also has served as a member of the Energy Department's Laboratory Operations Board. He was co-chair of NASA's Human Planetary Landing Systems Capabilities Road-mapping effort from 2004 to 2005. Since 2008, Schmitt has authored of numerous essays on public policy that can be accessed at <<http://americasuncommonsense.com/blog/>>.

Harrison Schmitt became chairman of the NASA Advisory Council in November 2005 and served until October 2008. He led the Council's deliberations on issues related to Aeronautics, Audit and Finance, Biomedicine, Exploration (human flight systems development), Human Capital, Science and Space Operations. He also instigated the Council's 2007 Workshop on Science Associated with the Lunar Exploration Architecture of NASA's Constellation Program.

Schmitt became a consultant to the Fusion Technology Institute at the University of Wisconsin in 1986, advising on the economic geology of lunar resources and the

engineering, operational, and financial aspects of returning to the Moon. He remains an Associate Fellow of Engineering at the University of Wisconsin - Madison, having taught "Resources from Space" from 1996-2004. He also has served on the staff of the Institute for Human and Machine Cognition of Pensacola, Florida. Related to his work at Wisconsin, Schmitt is the author of "Return to the Moon" (Springer-Praxis, 2006) that describes a private enterprise approach to providing lunar Helium-3 fusion energy resources for use on Earth.

Schmitt's became a Director of Orbital Sciences Corporation in 1983, serving as Lead Director in 2014 before that company's merger with the ATK Corporation. He is chairman of the Governance Committee of the merged company, Orbital ATK Corporation. Schmitt has served as a director of several public, private and non-profit corporations in the fields of mining, medical research and technology, banking, and laser systems. As a retired Director, he continues as an emeritus member of the Corporation of the Charles Stark Draper Laboratory. He also is a member of Southern Methodist University's Maguire Energy Institute's Board of Advisors.

Dr. Schmitt continues to consult, speak, and write on policy issues of the future; the science of the Moon and planets; and the history of space flight and geology, space exploration, space law, climate change and the American Southwest. In particular, he participates in research activities requiring geologic, petrographic, and stratigraphic synthesis of observations, photographs and samples returned from the Moon by Apollo missions and subsequent orbital remote sensing missions. He publishes regularly on lunar and planetary science research and aerospace and defense issues.

ORGANIZATIONS: The Geological Society of America (Honorary Fellow); The American Geophysical Union (Fellow); The American Association for the Advancement of Science (Fellow); The American Institute of Aeronautics and Astronautics (Fellow); Sigma XI; American Association of Petroleum Geologists (Fellow); The American Institute of Mining, Metallurgical and Petroleum Engineers (Honorary Member); New Mexico Geological Society (Honorary Member); The American Astronautical Society.

SPECIAL HONORS: Fulbright Fellowship in Norway (1957 to 1958); Kennecott Fellowship in Geology at Harvard University (1958 to 1959); Harvard Fellowship (1959 to 1969); Parker Traveling Fellowship at Harvard University (1961 to 1962); National Science Foundation Postdoctoral Fellowship, Department of Geological Sciences, Harvard University, (1963 to 1964); Johnson Space Center Superior Achievement Award (1970); NASA Distinguished Service Medal (1973); Fairchild Fellow, Caltech (1973 to 1974); California Institute of Technology, Distinguished Graduate (1973); Honorary Fellow of the Geological Society of America (1973); Arthur S. Fleming Award (1973); Republic of Senegal's National Order of the Lion (1973); Honorary Life Membership of New Mexico Geological Society (1973); Honorary Member of Norwegian Geographical Society (1973); Honorary Fellow American Institute of Mining, Metallurgical and Petroleum Engineers (1973); Honorary Fellow of The Geological Society, London (1974); International Space Hall of Fame (1977); Fellow American Institute of Aeronautics and Astronautics (1977); Engineer of the Year Award, National Society of

Professional Engineers, Legislative Recognition Award (1981); National Security Award, highest Civil Defense Award (1981); Nine Honorary Doctorates from United States and Canadian Universities; NASA Distinguished Public Service Medal (1982); Lovelace Award, Society of NASA Flight Surgeons (1989); G.K. Gilbert Award, Planetary Geology Division, Geological Society of America (1989); Award for Excellence, Presbyterian Healthcare Foundation (1990); Aviation Week Legend Award (2002); American Association of State Geologists Pick and Gavel Award (2008).. In recognition of past service, the U.S. Department of State in July 2003 established the Harrison H. Schmitt Leadership Award for U.S. Fulbright Fellowship awardees. He also traveled in Europe in 2009 as a speaker and specialist for the State Department. In 2007, Schmitt was awarded the first Eugene M. Shoemaker Memorial Award by Arizona State University and became the first recipient of the National Space Society's Gerard K. O'Neill Memorial Space Settlement Award. He has been awarded the 2010 inaugural Columbia Medal by the Aerospace Division of the American Society of Civil Engineers; the 2011 American Geological Institute's Medal in Memory of Ian Campbell for Superlative Service to the Geosciences; and the 2015 Lief Ericson Exploration Award by the Islandic Exploration Museum.

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Chairman SMITH. Thank you, Dr. Schmitt.
And, Lieutenant General Stafford.

**TESTIMONY OF LT. GEN. THOMAS P. STAFFORD,
GEMINI VI, GEMINI IX, APOLLO 10,
APOLLO-SOYUZ TEST PROJECT ASTRONAUT;
CHAIRMAN, NASA INTERNATIONAL
SPACE STATION ADVISORY COMMITTEE**

Lt. Gen. STAFFORD. Thank you.

Chairman SMITH. Make sure your microphone is on there. Okay.

Lt. Gen. STAFFORD. Checklist. Mr. Chairman, Ranking Member Johnson, members of the committee, I'm honored to appear before you today to discuss our nation's space program. In my opinion, the timing and the subject of this hearing are perfectly chosen.

One of the key issues confronting the new Congress and the new Administration will be how to go forward with restoring Americans' preeminence in space after what frankly for nearly eight years has been lost opportunities. And getting the program back on track is so important. The next steps will be to ensure the stability of the program.

We have had in recent years seen all too clearly the consequences of failure to carry out the long-term objectives. The changing of major programs with the change of new Administrations has been detrimental to the nation's space program. NASA's past is one of the nation's crown jewels and one of the things that has made America great. It is a wonderful projection of what I would term soft power to the rest of the world.

That encompasses nine Apollo missions to the Moon. Six of those were landings on the Moon. We have seven robotic spacecraft landings on Mars, the Hubble Space Telescope, the first rendezvous and landing on a near-Earth asteroid, robotic reconnaissance of every planet in our solar system, and the development of the space shuttle, and, with our international partners, the building and the operations of the International Space Station.

I and my colleagues on this panel have had the incredible privilege and the good fortune to be part of that history, Mr. Chairman. Unfortunately, it is history. NASA's presence today does not do justice to its past. Many of our greatest achievements are no longer to be seen in flight, but rather to be found only in museums. We have abundant plans to return to the Moon, establish a lunar base and instead, just recently, start to talk but only talk about going one day to Mars.

The next flagship science mission that we will have launched, the James Webb telescope, was started during the Bush Administration with nothing comparable initiated during the eight years of the previous Administration with the exception of a wonderful Congressional initiative to build the SLS and the Orion spacecraft. And I said last night at the meeting that the members of this committee and a similar committee in the Senate should be congratulated for taking the initiatives to say that America should go forward, and you all did a great job, just a wonderful job. I know it was—Bill Nelson was a leader for the Democratic side, Kay Bailey Hutchison, over here we have Mr. Gordon and Ralph Hall, whose picture I see

on the wall there, a great leader, and a lot of the staff like Robert Obermann recognized, and many others.

It was such a great effort by the Congress and this Committee in 2010 that set the umbrella that we are now proceeding in going forward. And we need—this future will turn return us to the Moon and then go on to an exploration of Mars.

The SLS can be useful for many large robotics spacecraft to the outer planets and may be useful to the Department of Defense. And we have done a lot of studies in the period of '90 and '91 I was asked by the Vice President to put together a large team to study how to go back to the Moon, go on to Mars in a way that is faster, better, and I'll use the word less cost, not cheaper. And so I gathered 45 people full-time. I had the commander of the space and missile system put together 150 part-time. We had inputs from academia, industrial firms from all over the United States.

And then for nearly 12 months we studied, and finally, the Vice President and I had a joint press conference in the White House and produced this book, which is the inputs of thousands of people called America at the Threshold still regarded by some as a Bible and a foundation. You can use variations of it, but that will take you back to the Moon and on to Mars.

And I know it's not been fashionable to talk about the Moon, but the Moon is important and we said—one of our architects—that we would go there and learn enough, you know, from the environment and do simulations, too, with Mars, things, not to take up too much of the funding but enough to go there and then on to Mars.

Thank you, Mr. Chairman.

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

Witness Statement

Hearing on "The Past, Present, and Future of NASA"

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

Rayburn House Office Building
Room 2318

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

16 February 2017

Chairman Smith, Ranking Member Johnson, and Members of the Committee: I am honored to appear before you today to discuss our nation's space program. In my opinion, the timing and subject of this hearing are perfectly chosen. One of the key issues confronting the new Congress and the new Administration will be how to go about restoring American preeminence in space after what have been, frankly, eight years of lost opportunities. And, after getting the program back on track, the next task than will be to ensure its stability. We have in recent years seen all too clearly the consequences of failure to carry out long term objectives. The changing of major programs with the change of new Administrations has been detrimental to the Nations space program.

NASA's past is one of this nation's crown jewels, one of the things that truly made America great. That past encompasses nine Apollo missions to the Moon and six manned landings, seven robotic spacecraft landings on Mars, the Hubble Space Telescope, the first rendezvous with and landing upon a near-Earth asteroid, the robotic reconnaissance of every planet in the Solar System, the development of the Space Shuttle and, with our international partners, the building of the international Space Station. I and my colleagues on this panel had the incredible privilege, and good fortune, to be a part of this history.

Unfortunately, it *is* history. NASA's present does not do justice to that past. Too many of our greatest achievements are no longer to be seen in flight, but rather are to be found only in museums. We have abandoned plans to return to the Moon and establish a lunar base, and instead talk -- but only talk -- about going one day to Mars. The next flagship science mission we launch, the James Webb Space Telescope, was initiated in the Bush Administration, with nothing comparable initiated during the eight years of the Obama Administration. Yes, we are building a heavy-lift launch vehicle, the SLS, that is comparable in performance to the Saturn V upon which Jack Schmitt and I have flown to the Moon. But in contrast to the Saturn V, which flew five times during an eleven-month period in 1968-69, we are planning to fly the SLS only once in every few years. We certainly need the SLS, but equally we need a space program designed to make good use of it.

We need a better future than this for NASA, and for the nation, in space. We need to return to the Moon and eventually go on for an expedition to Mars. The SLS can also be useful for large robotic spacecraft to the outer planets and may be useful to the Department of Defense.

The Trump Administration has been very busy in its first weeks in office, but despite this we have already seen some re-focusing on the Moon as the stepping stone to moving humanity into deep space. This is a welcome view. While the loss of preeminence in space was only one of the many ways in which the prior administration weakened American leadership in the world, it was one of the most profoundly noticeable, given the near-universal appeal of space exploration to the advanced nations of the world — otherwise known as “our competitors”. People everywhere want to be allied with leaders, and nothing that the United States has ever done bespeaks “leadership” more than being first and foremost on the space frontier. It benefits us in every way — geopolitics, trade, deal making, national security — in everything we do in the world.

The future of NASA and our nation in space depend upon setting a bold, immediate, a practical goal, a goal which will once again put the United States in first place on the world stage. That goal is the Moon. For a multitude of national security, economic, and scientific reasons, we cannot cede the space between Earth and Moon, nor the lunar surface itself, to China or other countries. However, International partnerships can certainly be developed once the objectives have been defined and authorized. When we do return to the Moon, we should structure the program to offer the best possible forward path to Mars, but the Moon must come first. That is not the course upon which we are presently embarked, and so it must change. This Congress, and this Administration, can be the ones to change it. Just like the Congress, in a great bipartisan effort, created the SLS and Orion programs.

Thank you. I would be happy to answer any questions you may have.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Chairman SMITH. Thank you, Lieutenant General Stafford.
And, Dr. Stofan.

**TESTIMONY OF DR. ELLEN STOFAN,
FORMER NASA CHIEF SCIENTIST**

Dr. STOFAN. Thank you for inviting me before this Committee today. As the Chairman remembers, I was delighted to come and speak with you about life in the universe in 2015. Today, I want to share my optimism about where NASA currently stands and where it's headed.

Over the next few years, I hope to join members of this committee to watch American astronauts launch from Florida aboard American spacecraft, feel the roar of the largest rockets since Apollo leave the ground, have my perspective of the universe changed by data from the James Webb Space Telescope, and have people's lives improved here on Earth by the continued observation and study of our own planet, and be much closer to answering that question "Are we alone?"

NASA's planetary, earth science, astrophysics, and heliophysics programs continuously rewrite textbooks with their discoveries. These areas of science are deeply connected and are leading us to discover an earthlike planet around another star. NASA's Kepler space telescope has found over 3,000 planets around other stars, and telescopes launched in the coming years will further the search.

Which brings me to Mars. Mars is the most likely place beyond Earth to have harbored and may still harbor life. Other targets include Europa, Enceladus, and Titan, but Mars is the closest, the most accessible for exploration, and the most like our own Earth. Finding fossil evidence of past life on Mars is not going to be easy, and I strongly believe it will take Mars astronauts to find proof of life.

When I started as Chief Scientist, I was moving houses and I found an old newspaper interview with my father that he did when he became head of the space station in 1986. He talked about how the space station would lay the groundwork for humans to get to Mars in 20 years. I read this not long after having given a speech saying the exact same thing. Mars will always remain 20 years in the future without bipartisan support and the commitment to make it happen. It can be done without major increases in budget and without revolutions in technology. It just needs focus, constancy of purpose, and continued leadership.

NASA has a sustainable plan to get humans to Mars orbit by 2032 and land thereafter. This plan is built upon the research NASA does on the space station to prepare for longer duration of spaceflight and NASA's development of deep space capabilities. The next step is a habitat in lunar orbit in the mid-2020s to learn about the higher radiation environment and finalize development of long duration life-support systems.

If international partners or the private sector want to go to the surface of the Moon, as the commercial sector is well on its way to doing, NASA is already supporting these efforts. In both low-Earth orbit and the surface of the Moon, the 2020s will be the decade of NASA moving out and the private sector moving in. By 2032

we'll be ready for the first human roundtrip mission to Mars with the surface landing to follow in the late 2030s. Unlike past plans, this plan is sustainable as it assumes a level of spending consistent with post-Apollo reality. Should Congress want to up the relative spending, this timeline could be accelerated.

Mars is the goal for human exploration and it is key that we keep our eyes on this prize, doing things we have never done before, pushing the limits. This is the proper role and should be the focus of NASA. When nations try to do great things, tough things that no one has done before, they move their country forward economically, strategically, inspirationally.

But it's important to remember that the only planet we can actually live on is this one. From space, we are able to collect deep and continuing data sets of Earth that are directly beneficial to our economy, our national security, and to each one of us every day. Data gathered from NASA's Earth-observing satellites and aircraft, coupled with NASA's support of fundamental research and analyses of these data enable us to better understand and predict our weather, make better land-use and urban-planning decisions, and respond to natural disasters and wildfires. Satellite observations of crops help us predict food security needs not just in this country but around the world.

NASA data are helping us understand the rapid rate of change we see from melting sea ice in the Arctic, the loss of ice in Greenland and western Antarctica, changing patterns of vegetation, and rising sea levels.

Water is a precious resource and a potential source of world conflict. Our satellites today are giving us an unprecedented view of the global water cycle. These data help farmers plan how to water crops, water resource managers plan for and deal with too much or too little rain, and warn us of possible droughts or floods.

As Chief Scientist, I spoke to schoolkids here and around the world. NASA truly does inspire the next generation. They see NASA as a shining example of American ingenuity and leadership, American can-do.

NASA has accomplished great things and now reaches to do great new things: find life on other worlds, walk on the surface of Mars, use our space data to help sustain and prosper life here. It just takes commitment and focus. With your support of NASA, you don't have to wait for the future to happen. You can create it. Thank you.

[The prepared statement of Ms. Stofan follows:]

HOLD FOR RELEASE
UNTIL PRESENTED BY WITNESS
February 16, 2017

Statement of
Dr. Ellen Stofan
Planetary Scientist, Former Chief Scientist of NASA

Before the
Committee on Science, Space and Technology
US House of Representatives

Thank you for inviting me before this committee today. As the chairman remembers, I was delighted to come and speak about life in the universe with you in 2015.

As a planetary scientist who has worked at the Jet Propulsion Laboratory, at a university, at a small company, and at NASA, I can tell you that the strength of NASA lies in its people and its vision and mission: reaching for new heights and revealing the unknown for the benefit of humankind. At NASA, engineers, technologists and scientists work together to answer fundamental questions about the nature and fate of this planet, the solar system, the universe, how to move humans outward into the solar system, how to safely advance our aeronautics enterprise, and determine if there is life beyond Earth. These might seem like disparate challenges - but they are fundamentally linked in not just why we do them, but how we do them. NASA has excelled at this for over fifty years, and the agency truly stands on the brink of discovering life beyond this world, of moving humans to Mars, of safeguarding life on this planet through knowledge of our complex earth systems, and ushering in a new age of more efficient, safer air travel.

NASA's origin, and indeed, the first "A" in NASA, is aeronautics. Every U.S. aircraft flying today and every U.S. air traffic control tower uses NASA-developed technology

in some way. While there is great public excitement about the growing space industry, NASA is also leading the way on several revolutions in aeronautics. NASA is developing the technologies that will allow the Nation's air traffic control system to operate more safely and efficiently, even as air travel continues to grow significantly. These technologies will cut travel times and delays for passengers, reduce fuel use and emissions, and create significant savings to airlines. NASA is also at the forefront of the unmanned aerial vehicle, or drone, revolution. In close coordination with the FAA, NASA is developing the technologies that will allow the safe integration of these systems into the national airspace. In the last year, NASA has announced plans to work closely with U.S. industry to develop the next generation of experimental aircraft. These "X-planes" will test new technologies that will make air travel faster, safer, and more efficient. Imagine traveling anywhere in the world in six hours? Or imagine a hyperefficient and quite electric airplane? NASA is already working on X-planes to do just that. Finally, NASA's Aeronautics program plays an important role researching and testing hypersonic and supersonic principles and technologies. This is a critical area of research in support of our national security agencies, but also important to understanding how spacecraft can safely enter the atmosphere of Earth and Mars.

All of the science at NASA- planetary science, earth science, astrophysics and heliophysics- allow us to daily rewrite textbooks as our spacecraft data reveal how our universe works. Not only all of these areas of science are deeply connected, they are all necessary to achieving one of my passions as a scientist – discovering an Earth-like planets around another star, an Earth 2.0. NASA is embarked on this great search, but it requires knowing how this planet works and understanding why we only have one current Earth in our own solar system, how habitable planets interact with their parent star, and how planetary systems form and change over time. All four areas of science at NASA help us answer these questions, pushing the boundaries of human knowledge toward that ultimate discovery of an Earth 2.0.

As a child, I learned about the nine planets of our solar system, and later learned to live with only eight. Over the past three years, the Kepler space telescope has found over 3000 planets around other stars, looking at only a very small portion of our galaxy. This tells us that just about every star we see in the night sky has a planetary system. Later this year, NASA will launch a follow-on to the Kepler mission, the Transiting Exoplanet Survey Satellite or TESS, that will find a planet in the habitable zone around nearby stars. Shortly after that, the next great observatory, the James Webb Space Telescope will launch and allow us to analyze the atmospheres of some of these habitable zone planets, looking for gases like carbon dioxide, methane, or water that could indicate potential habitability. When I talk to students, I tell them that when I was their age I wanted to grow up to study our nine planets- but now they will have thousands, each one helping us to answer fundamental questions we have on the workings of our own planet. For whether it is the study of Venus, Saturn's moon Titan, or planets around other stars, we look to other worlds to better understand the physical processes that govern our own world. For example, I study volcanoes on Venus and seas on Titan to help us better constrain how volcanoes erupt and how seas interact with atmospheres on all planets, including Earth.

When we look at other planets, it always comes back to the fundamental question of habitability - Are we alone? Our studies of other planets have informed us that the habitable zone is not just a place, but it can also be a time. For example, early in their histories both Venus and Mars were likely to be habitable. But just like in the Goldilocks story, Venus became too hot and Mars became too cold, while the Earth has persisted in being able to maintain moderate temperatures to allow liquid water to be stable on its surface. It is this liquid water that we believe to be critical to the evolution and sustenance of life. On Mars, our robotic rovers and orbiters have provided data that tells us that water was stable for very long time periods- as much as a billion years- on its surface early in its history, about 3 billion years ago. This was the same time period during which life evolved here on Earth in the oceans, formed from the building blocks of life- amino acids- that have been delivered all

over the solar system by comets and asteroids. The conditions on Mars were so similar to those on Earth that astrobiologists look at Mars as one of the most likely places beyond Earth to have harbored- and maybe still harbor - life. Other targets in our solar system include the watery worlds of Europa and Enceladus, and my favorite Titan, with its seas of liquid hydrocarbons. But Mars is the closest, and the most accessible for exploration—and the most like our own Earth.

After about a billion years of favorable conditions on Mars, the planet lost its magnetic field, its unprotected atmosphere began to be stripped away by the solar wind, and Mars' water retreated underground, was lost to space, and froze into its small polar caps. Life either went extinct, or retreated underground with the water. Finding fossil evidence of past life on Mars is not going to be easy, and I strongly believe it will take Mars astronauts to find indications of life. Their work on the red planet will find not just indications of life, but ample evidence to help us understand the similarities and differences between life here on Earth and life that evolved on another world, and the implications of that for us, and for life beyond our solar system.

When I started as Chief Scientist, I was moving houses and sorting through some old files. I grew up in a NASA family and I found an old newspaper interview with my father that he did when he became head of the space station in 1986. His excitement came through in the interview as he talked about how the space station would lay the groundwork for humans to get to Mars in 20 years. I read this not too long after having given a speech saying the same thing -- over 20 years later. Mars will always remain twenty years in the future for NASA without bipartisan support and the commitment to make it happen. It can be done without major increases in budget and without revolutions in technology. It just needs focus, a constancy of purpose, and leadership.

NASA has never been closer to being able to send humans to Mars than today. NASA has a sustainable plan to get humans to Mars orbit by 2032, and land thereafter.

This plan is built on the research NASA does every day on the International Space Station to prepare humans for longer duration spaceflight. It is built upon the progress NASA has made in the development of the Space Launch System and Orion. By the mid-2020's, NASA's work on the ISS will be largely complete and SLS and Orion will be ready for work. The next step is then a habitat in orbit around the moon by the mid-2020s, where NASA can test what will be the prototype for a Mars transfer vehicle, the next step in living and operating independently from the Earth. In the vicinity of the moon, we can learn about the higher radiation environment, learn distant operations, and finalize the development of long-duration life support systems needed for the 2-3 year trip to Mars and back. If the international partners or the commercial sector want to go to the surface of the Moon, as the commercial sector is well on its way to doing, NASA will be able to participate in those efforts. In fact, NASA is already supporting some of these commercial lunar efforts through its Advanced Exploration Systems division. But in both low Earth orbit and on the surface of the Moon, the 2020's will be the decade of NASA moving out, and the private sector moving in.

By 2032, NASA will be ready for the first human round-trip mission to Mars, starting out with an orbital mission like we did with Apollo. Depending on budget and technology readiness, a surface landing should follow in the late 2030s. Entry, descent and landing (EDL) technologies are still the tallest tent pole in humans to the Mars surface, and NASA looks forward to partnering with SpaceX on Red Dragon to move those technologies forward. In addition, a round-trip demonstration returning a sample from Mars in the 2020s would help push EDL technologies and prepare us for a human landing as soon as possible.

As the National Academies concluded in their most recent study of human spaceflight, Mars is the goal for the human exploration program and it is key that we keep our eyes on this prize. Doing things we have never done before, pushing the limits- this is the proper role and should be the focus of NASA. This big push is what will enable the next generation of tech spinoffs to be capitalized on by the private

sector. With focus and determination, we are on our way to make this happen. When nations try to do great things- tough things- that no one has done before- they move their country forward, economically, strategically, inspirationally.

But as exciting as it is to talk about humans to Mars, it is important to remember that the only planet we can actually live on is this one. When I study planets, it always comes back to the question of Earth – how can we use this information to improve life here. Ours is a complex planet with oceans, a biosphere, and an atmosphere interacting in ways that we can uniquely study from the vantage point of space. From space, we are able to collect deep and continuing data sets of Earth that are directly beneficial to our economy, our national security, and to each one of us everyday.

The data gathered from NASA's earth observing satellites and aircraft, coupled with NASA's support of fundamental research and analysis of this data, enables us to better understand and predict our weather, more efficiently grow our crops, make better land use and urban planning decisions, and respond to natural disasters and wildfires. Satellite observations of crops help us predict food security needs not just in this country, but around the world, which is critical for national security. Our satellites and airborne data are helping us understand the rapid rate of change we see in the Arctic from melting sea ice, the loss of ice mass in Greenland and western Antarctica, changing patterns of vegetation, and rising sea levels. Our satellites help us to monitor storms, gain understanding of how hurricanes develop and strengthen, and provide the next generation of instrumentation for better weather forecasting.

Water has always been and always will be a precious resource, and a potential source of world conflict. Our satellites today are giving us an unprecedented view of the global water cycle. GPM tracks precipitation around the globe, JASON-2 warns us of El Nino or La Nina and monitors sea level, SMAP provide information on soil moisture and GRACE tells us whether and how much groundwater is being depleted,

or too saturated- warning us of possible floods to come. IceBridge helps us understand what is going on at the poles until IceSAT 2 launches, and the Surface Water Ocean Topography mission in 2021 will be able to monitor lake and river levels- giving us complete intelligence on the water cycle- not just here, but around the world. These data aren't just important for scientists trying to understand our water cycle- these data help farmers plan how to water crops, help water resource managers plan for and deal with too much or too little rain, and help warn us of possible droughts or floods in countries around the world.

For example, NASA developed a system that processes satellite data to track field-by-field water use to help water managers balance their water resources. This system is now being used by water managers in fifteen states, including Florida, Texas, California, and Oregon. A smartphone app version has been developed to get the same field-scale maps of water consumption to farmers.

None of what NASA does is possible without a constant emphasis on technology-changing the way we do things by investing in the future. From investments in small spacecraft and instrument technologies that have helped lead to the revolution in commercial industry of small spacecraft to technologies that have helped humans live on the ISS that have spun off things ranging from nutritional supplements in all baby formulas to water purification systems used in disaster zones, every NASA investment in technology is an investment in the US economy that typically returns much broader benefits to humankind.

Over the last several years as Chief Scientist, I had the opportunity to represent NASA, speaking to school kids not just in this country but all around the world. NASA truly does inspire the next generation- the Mars generation. They see NASA as a shining example of American ingenuity, American leadership- American can do. NASA has accomplished great things- and NASA now reaches to do new great things- find life on other worlds, walk on the surface of Mars, use our space data to help

sustain and prosper life here. It just takes a commitment and focus. With your support of NASA, you don't have to wait for the future to happen, you can create it.

Dr. Ellen Stofan is the former Chief Scientist of NASA (2013-2016), serving as principal advisor to the NASA Administrator on the agency's science-related strategic planning and programs. She is an Honorary Professor in the Department of Earth Sciences at University College London and co-chair of the World Economic Forum Space Council. Her research focuses on the geology of Venus, Mars, Saturn's moon Titan, and Earth. Stofan has a PhD and MSc from Brown University and a Bachelor of Science degree from the College of William and Mary. She has published extensively, and received many awards and honors including the Presidential Early Career Award for Scientists and Engineers. She is an associate member of the Cassini Mission to Saturn Radar Team, and proposed a mission to NASA to land a boat on a sea on Titan. Stofan has received honorary degrees from Washington and Jefferson College, Meredith College and the College of William and Mary. She is the former Chair of the College of William and Mary Foundation Board.

Chairman SMITH. And thank you, Dr. Stofan.
And, Mr. Young.

**TESTIMONY OF MR. TOM YOUNG,
PAST DIRECTOR, GODDARD SPACEFLIGHT CENTER;
PAST PRESIDENT/COO, MARTIN MARIETTA;
PAST CHAIRMAN, SAIC**

Mr. YOUNG. Thank you, Mr. Chairman.

NASA's accomplishments during the six decades of its existence have been extraordinary. It's hard to imagine a public or private sector organization that has accomplished more, given the level of difficulty of the NASA endeavors, including the array of accomplishments or observations that have revolutionized our understanding of our sun and planetary home, landers and rovers on the surface of Mars, robotic visits to all the planets of our solar system, telescopes that have looked to billions of years back in time and also have discovered hundreds of planets around other stars, humans walking on the surface of the Moon, and the development and operation of a space station that is a technological marvel. Truly, NASA has repeatedly turned the perceived impossible into reality. NASA's accomplishments have filled our books and electronics systems with new knowledge about our sun, Earth, our solar system, the universe, and humans operating in space.

NASA has been a source of enormous national pride and international prestige. NASA has inspired our youth, as well as people of all ages. When we make the observation that great nations do great things, the NASA contributions are high on the list of great things. NASA has done its part in making our nation great.

One of the more impressive accomplishments of NASA has been the human exploration program, specifically, humans walking and riding on the surface of the Moon while exploring and enhancing our scientific understanding of our nearest neighbor. While the lunar endeavor was spectacular, it also highlights a disappointment that no boots-on-the-ground human exploration venture has been accomplished since Apollo 17 44 years ago. We have the opportunity to rectify this disappointment in the next couple of decades.

The enormous capability that has been developed from the multitude of successes, as well as disappointing failures, is often overlooked when assessing the accomplishments of the last six decades. NASA has an enormous bank of knowledge, expertise, and experience, largely resident in the people of NASA.

It would be wrong to equate the accomplishments of the last six decades to NASA alone. The U.S. aerospace industry with implementation capabilities second to none has been an incredible partner. The industry has continued to develop its capabilities to implement the most challenging of endeavors.

The third leg of this national capability is the depth of talent that resides in our laboratories and academic institutions. I believe the reason for the remarkable success of the last six decades is that we have fully utilized the continuity of expertise resident in NASA, in combination with the implementation capability of industry and the talent and capabilities in our laboratories and in academia.

Space is a one-strike-and-you're-out business. It takes the absolute best of all sectors to assure success. Our space initiatives are focused on exploration and science. To maximize our exploration and scientific results also requires our absolute best. These lessons learned will be critically important to the future of NASA.

So where is NASA today? The trend of challenging endeavors with anticipated incredible results continues unabated. The James Webb Space Telescope, SLS, Mars 2020 is the first step in returning samples from the surface of Mars to Earth and Orion are but examples.

In addition to rigorously implementing the approved NASA program, our most important responsibility is developing a strategy for the future. This is currently critical because the challenges and opportunities are large and significant. With exceptional leadership, focus, commitment, and support, the future can be even more rewarding than the past six decades. It is also possible that we can spend a lot of money and accomplish little.

There is a set of great questions that can guide our thinking about the future. Are we alone? What is dark energy and dark matter? Is it possible and practical for Mars to be a lifeboat or a second home for the human race? These are certainly—there are certainly other great questions, but these are opportunities to start the discussion. I believe we can answer each of these questions in the next few decades.

I suspect we have all looked at the night sky and wondered if we're alone or if we have neighbors waiting to be discovered. The fact that we don't understand 90 percent of the universe says the opportunity for awesome discoveries awaits us.

In discussing the NASA future, I'll separate my comments into science and human spaceflight. The science element is well-planned and focused upon the highest-priority endeavors. The National Academies' Decadal Surveys are well done with broad participation of the scientific community. NASA effectively utilizes the Decadal Surveys to establish direction for the science enterprise.

The current and future strategic state of human spaceflight is cloudy, and current NASA budgets—approximately \$9 billion—is allocated to human spaceflight. Over the next two decades, that accumulates to approximately \$180 billion, which should support significant accomplishments.

My view is that there are too many potential paths competing for the available resources, making it imperative that difficult program decisions be made. About half the current budget is allocated to low-Earth-orbit endeavors which consists of the International Space Station, commercial cargo, and commercial crew. The other half of the budget is for human exploration, which includes SLS and Orion. A \$4.5 billion budget is clearly inadequate for a capable human exploration program. A choice must be made and made soon between LEO and exploration.

Additionally, there is discussion of NASA leading or being the catalyst for commercializing LEO. There are also plans for a cislunar space endeavor of approximately a decade duration. Date—debate continues as to whether the Moon or Mars should be the exploration objective.

Are we going to have a credible human exploration program? Assuming the answer is yes, we needed to focus our physical and human resources on making exploration a credible reality. Failure to decide between these competing options will result in significant resources being spent and not—could not have a credible exploration program.

My personal conviction is the primary human spaceflight goal for the future NASA should be exploration with boots on the ground on either the Moon or Mars. I believe Mars is the most compelling objective. I believe the commercialization of LEO should be the responsibility of the private sector with NASA providing technological support but not management or financial support. Above all else, a detailed plan for the human exploration program is mandatory.

A future NASA focused upon the great questions with a science portfolio guided by the National Academies' Decadal Survey and a human exploration program concentrating on the human exploration of Mars can be responsive to the axiom that great nations do great things. NASA's future can be even more exciting and rewarding than NASA's extraordinary past. Thank you.

[The prepared statement of Mr. Young follows:]

TESTIMONY TO THE COMMITTEE
ON
SCIENCE, SPACE AND TECHNOLOGY

SUBCOMMITTEE ON SPACE

FEBRUARY 16, 2017

A. THOMAS YOUNG

Chairman Babin and Committee members, I am pleased to have the opportunity to present my views on NASA: Past, Present and Future. My testimony is focused on NASA's science and human spaceflight programs. I do not mean to diminish the role NASA has played and continues to play in advancing aeronautics research which is very important to our country.

NASA's accomplishments during the six decades of its existence have been extraordinary. It is hard to imagine a public or private sector organization that has accomplished more, given the level of difficulty of the NASA endeavors. Included in the array of accomplishments are observations that have revolutionized our understanding of our sun and planetary home, landers and rovers on the surface of Mars, robotic visits to all of the planets of our solar system, telescopes that have looked billions of years back in time and also have discovered hundreds of planets around other stars, humans walking on the surface of the moon, and the development and operation of a space station that is a technological marvel.

Truly NASA has repeatedly turned the perceived impossible into reality. NASA's accomplishments have filled our books and electronic systems with new knowledge about our sun, earth, our solar system, the universe and humans operating in space. NASA has been a source of enormous national pride and international prestige. NASA has inspired our youth as well as people of all ages. When we make the observation that "Great Nations Do Great Things," the NASA contributions are high on the list of great things. NASA has done its part in making our nation great.

One of the more impressive accomplishments of NASA has been the human exploration program, specifically humans walking and riding on the surface of the moon while exploring and enhancing our scientific understanding of our nearest neighbor. Returned lunar samples are still yielding new data even after more than four decades. While the lunar endeavor was spectacular, it also highlights a disappointment that no "boots on the ground" human exploration venture has been accomplished since Apollo 17, 44 years ago. We have the opportunity to rectify this disappointment in the next couple of decades.

The enormous capability that has been developed from the multitude of successes, as well as disappointing failures, is often overlooked when assessing the accomplishments of the last six decades. NASA has an enormous bank of knowledge, experience and expertise, largely resident in the people of NASA.

It would be wrong to equate the accomplishments of the last six decades to NASA alone. The U. S. aerospace industry with implementation capabilities second to none has been an incredible partner. The industry has continued to develop its capabilities to implement the most challenging of endeavors. The third leg of this national capability is the depth of talent that resides in our laboratories and academic institutions.

I believe the reason for the remarkable success of the last six decades is that we have fully utilized the continuity of expertise resident in NASA in combination with the implementation capability of industry and the talent and capabilities in our laboratories and academia. Space is a "one strike and you are out" business and it takes the absolute best of all sectors to assure success. Our space initiatives

are focused on exploration and science. To maximize our exploration and scientific results also requires our absolute best. These lessons learned will be critically important to the future NASA.

Where is NASA today? The trend of challenging endeavors with anticipated incredible results continues unabated. The James Webb Space Telescope, SLS, Mars 2020 as the first step in returning samples from the surface of Mars to earth and Orion are but examples.

In addition to rigorously implementing the approved NASA program, a most important responsibility is developing a strategy for the future. This is currently critical because the challenges and opportunities are large and significant. With exceptional leadership, focus, commitment and support the future can be even more rewarding than the past six decades. It is also possible that we can spend a lot of money and human capital and accomplish little.

There is a set of great questions that can guide our thinking about the future.

- * Are we alone?
- * What is dark energy and dark matter?
- * Is it possible and practical for Mars to be a lifeboat or a second home for the human race?

There are certainly other great questions, but these are appropriate to start the discussion. I believe we can answer each of these questions in the next few decades. I suspect we have all looked at the night sky and wondered if we are alone or do we have neighbors waiting to be discovered. The fact that we don't understand approximately 90% of

the universe says the opportunity for awesome discoveries awaits us. I suspect we all have enormous faith in the human race on earth; however, my space project training says one should always have a contingency plan for a potential catastrophe. If we want a second opinion we should check with the dinosaurs. Mars appears to be the only potential alternative.

In discussing the NASA future, I will separate my comments into science and human spaceflight. The science element is well planned and focused upon the highest priority endeavors. The National Academies decadal surveys are well done with broad participation of the scientific community. NASA effectively utilizes the decadal surveys to establish direction for the science enterprise.

A simple check on the quality of any endeavor is the merit of activities that are beyond the funding limits of the endeavor and not being pursued. For science the programs just beyond the funding barrier are of equal quality to those being funded. The conclusion of this simple test is that additional funding would allow the inclusion of equally high value opportunities and enhance the value of the overall portfolio.

The current and future strategic state of human spaceflight is cloudy. In current NASA budgets, approximately 9B\$ is allocated to human spaceflight. Over the next two decades that accumulates to approximately 180B\$ which should support significant accomplishments. My view is that there are too many potential paths competing for the available resources making it imperative that difficult program decisions be made. About half of the current budget is allocated to Low Earth Orbit (LEO) endeavors which consist of the

International Space Station, commercial cargo and commercial crew. The other half of the budget is for human exploration which includes SLS and Orion. A 4.5B\$ annual budget is clearly inadequate for a credible human exploration program. A choice must be made and made soon between LEO and exploration. Additionally, there is discussion of NASA leading or being the catalyst for commercializing LEO. There are also plans for a sislunar space endeavor of approximately a decade duration. Debate continues as to whether the moon or Mars should be the exploration objective.

Are we going to have a credible human exploration program? Assuming the answer is yes, we need to focus our fiscal and human resources on making exploration a credible reality. Failure to decide between these competing options will result in spending significant resources and not having a credible exploration program.

My personal conviction is the primary human spaceflight goal for the future NASA should be exploration with "boots on the ground" on either the moon or Mars. I believe Mars is the most compelling objective. I believe the commercialization of LEO should be the responsibility of the private sector with NASA providing technological support but not management or financial support. Above all else a detailed plan for the human exploration program is mandatory.

A future NASA focused upon the great questions with a science portfolio guided by the National Academies decadal surveys and a human spaceflight program concentrating on the human exploration of Mars, can be responsive to the axiom that "Great Nations Do Great Things." NASA's future can be even more exciting and rewarding than NASA's extraordinary past.

A. Thomas Young

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

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

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

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

Chairman SMITH. Thank you, Mr. Young.

I'll recognize myself for questions. And, Dr. Schmitt, let me address the first one to you. You set some great worthy goals, landing again on the Moon in I think 2025, landing on Mars in 2040, only 25 years from now. What does NASA need to do that it is not doing now to get to Mars by 2040 and land astronauts on that surface?

Dr. SCHMITT. Mr. Chairman, I think the main demand to accomplish that would be to put together a management system in NASA that is comparable to what ultimately evolved for Apollo. That system would include an average age that's younger than NASA today. Young people provide that courage and patriotism and imagination that really made Apollo possible.

During the Apollo 13 crisis, Gene Kranz did a survey when he had a moment of the ages of people in mission control, and the average age at that time was 26. The nuclear Navy keeps itself young, and it's well worth I think looking on how that's done. Of course, it's a military program and they have different rules than the civil service, but still, I think it's important for the long-term future of NASA to find a way in which it can keep itself young.

Chairman SMITH. Okay. Good. Thank you.

Dr. SCHMITT. That's one of many, but management is going to be the key I think.

Chairman SMITH. Okay. Thank you. Lieutenant General Stafford, just to take it to the shorter-term, say the next 4 or eight years, what recommendations do you have for Congress and NASA as to what we can accomplish in that time frame? And let me add that yesterday, NASA announced—I don't know if you read it or not or heard it or not, but NASA announced that they are going to conduct a study about the very real possibility in two years of sending astronauts on SLS and do a Mars flyby. They're just conducting the study. They didn't commit to it 100 percent yet but—I'm sorry, Moon flyby, not a Mars flyby. What do you think—that got your attention, didn't it? A Moon flyby in two years with astronauts on SLS. But what do you think of that idea? What do you think we could be doing in the next 4 to 8 years?

Lt. Gen. STAFFORD. Mr. Chairman, the one thing again is continuity and adequate management and budget resources. And it's so important I think that people understand why we need a big booster. And for the new members of the Committee here to emphasize that when I lifted off to go to the Moon, when Jack Schmitt lifted off, our—the total mass was about 6.25 million pounds. In 11 minutes we put approximately 300,000 pounds into orbit or a little—I had about 138 metric tons and Dr. Schmitt had a little bit more on his. And then we kicked out. And most of it was the third stage with the fuel in it, which was only 4.8 percent of that giant booster.

And what was the useful payload? The lunar module and the command module was a third of that, so we had 1.6 percent that went on to do that mission to land on the Moon, so this is why you need a big booster. You'll see all the different ideas. We'll take small ones and put them together and all this. Well, we've been through it and we've studied it from A-to-Z. It doesn't work.

Chairman SMITH. Okay.

Lt. Gen. STAFFORD. We're started down the right path and I think—

Chairman SMITH. Good to hear. Okay. Thank you, Lieutenant General Stafford.

And, Dr. Stofan, you have a special interest in discovering life in the universe elsewhere outside of our solar system, and I have a special interest in that as well. I think it's a fascinating subject. What are the prospects of discovering some form of life—vegetative, sentient, whatever it might be—elsewhere in the universe outside our solar system? And do we have any hope, say, in the next ten years, with any of our telescopes or next-generation telescopes of picking up spectra from an earthlike planet, for example?

Dr. STOFAN. Well, as you know, we have all of the targets from Kepler of planets around other stars, some of which lie in the habitable zone, and then obviously we have the TESS, the Transiting Exoplanet Survey Telescope, that will launch in about a year-and-a-half that will, we think, find a habitable planet—a potentially habitable planet about one a month for its three-year mission.

That means we're going to have a lot of candidates for the James Webb Space Telescope, which has the ability to look at the atmospheres of planets around other stars. So James Webb will hopefully start looking for gases like carbon dioxide, methane, oxygen, water that would be potentially indicative of habitability. But it's really going to take that next generation of space telescope, I think, to get us from identifying potentially habitable worlds to being a lot more confident that that world is actually potentially inhabited.

Chairman SMITH. Okay.

Dr. STOFAN. So for right now, I think our focus really need to be on our own solar system—Mars, Europa, Enceladus, Titan—where we can really push this question of—

Chairman SMITH. Right.

Dr. STOFAN. —what are the bounds of habitability, what are the chances of life beyond Earth by really looking at our own solar system.

Chairman SMITH. Right. And as you know, NASA has plans for Europa as well, too.

Dr. STOFAN. Yes.

Chairman SMITH. With the indulgence of my colleagues, let me squeeze in one last question and it is this: Mr. Young, you mentioned the constraints of the budget. You said we have limited resources, all of which is true, so therefore, what can NASA do best, what can the private sector do best, in order to maximize the use of our resources?

Mr. YOUNG. I have a couple answers to your question, which is a very good one. First off, I really believe we've got—

Chairman SMITH. Will you pull the mic towards you just a little bit? Thank you. There.

Mr. YOUNG. I really believe we've got to make the hard decisions. We cannot distribute the limited budget over all of the possibilities that exist, even though they all have merits and we expect to accomplish them all. So we've really got to establish priorities, number one.

The second thing is that I—having spent a bit of my life both in NASA and also in the private sector, I have some appreciation for both sides of the equation. NASA has enormous, what I call continuity capability, to apply to a given space exploration kind of an endeavor. Industry goes much more from project to project. It has enormous implementation capability. And I think we need to recognize what the strengths are that both groups bring to this particular problem.

And when we're able to marry the enormous continuity capability that NASA has and the implementation capability that industry has, we seem to really be able to accomplish an awful lot. When we choose to tie one of their hands behind them and say, look, you know, we're only going to use part of your capabilities, that's when we usually end up with not very satisfactory results.

Chairman SMITH. Okay. Thank you, Mr. Young.

That concludes my questioning, and I'll recognize the Ranking Member, Ms. Johnson, for her questions.

Ms. JOHNSON. Thank you very much, Mr. Chairman.

Let me thank all of you for your testimony. It's been very enlightening to me. And I guess my question now is I'd like to hear from each of you what you would recommend that we focus on for the next few years, and if we choose to continue to focus on all aspects—the Station, as well as pursuing Mars—how much money do you think we need?

Dr. SCHMITT. Congresswoman, the—that's a tough question—

Ms. JOHNSON. Yes.

Dr. SCHMITT. —because as I said in my oral testimony and believe very strongly that if you decide you're going to have a deep space human spaceflight program that includes the Moon, Mars, and deep space itself, that needs to be a focus. And there are, I think, other ways in which we can implement the very fine programs that NASA has undertaken in the years largely since Apollo, but it really—it takes management focus, I think, to make sure that you're going to be successful and to deal with the geopolitical realities that drive you in that direction.

Ms. JOHNSON. Thank you.

Dr. SCHMITT. So I think the Congress needs to examine just what is going to be required legislatively in order to provide that focus.

Ms. JOHNSON. Thank you.

Lieutenant General Stafford?

Lt. Gen. STAFFORD. Ms. Johnson, the—as pointed out by the Chairman, we have so much money for the exploration, which includes, you know, space station and other things. And we've answered a lot of questions that were identified in this study and other studies. One thing is how do you close the loop to reuse the air? Every human being here at sea level, average weight, uses about 2.2 pounds of oxygen a day. You need about 6 pounds of water a day and then approximately 1.5 pounds of food a day. Probably some people get more than that. But the main thing is the recycling. And the Russians started it. We started it really in Skylab, and now it's working very well on the space station.

But, remember, as I pointed out, when Dr. Schmitt and I flew to the Moon, our useful payload was 1.6 percent of what we lifted off with. So if you have a pound—1.6 of oxygen, it's going to take

100 pounds of gross weight to start with. So the space station has answered a lot of that. It's been up there for quite a while. And by 2024 to me it should answer most of the questions that have been required.

And also, we've determined with the—we call it the ARED, astronaut exercise resistant device, how to keep the bone mass up, the muscles up, and we've really come a long way. The station has really answered a lot of the questions. So some of that money could be used to go forward.

Ms. JOHNSON. Thank you.

Dr. STOFAN. I think the focus should be—remain more or less as it is, implementing the Decadal Surveys; supporting basic research and technology development, as NASA does across its directorates; supporting aeronautics and the great support it gives to the aeronautics industry in this country; and to follow NASA's plan, ISS to 2024, support SLS and Orion, lunar habitat in the mid-2020s, Mars orbit in 2032. This is an achievable plan, and again, it more or less fits within NASA's existing budget. This does not require huge increases in budget.

Ms. JOHNSON. Thank you.

Mr. YOUNG. I believe that if we continue on the current course with the multiple paths that we're on and the current budget, the committee hearing that'll take place ten years from now will say what a disappointing decade we had and that we will be negligibly closer to landing humans on Mars than we are today.

So I think we have two real decisions to make. One is to narrow the number of paths and to focus on the highest-priority item. The second is—you asked about resources, and this is always dangerous and I haven't done an analysis, but if I had to answer your question, if you want to keep doing what we're doing today, what do you need? \$10 billion-plus more per year.

Ms. JOHNSON. Thank you very much. My time is expired.

Chairman SMITH. Okay. Thank you, Ms. Johnson.

I've always felt we ought to have a pin that says one percent for NASA, which would be doubling our current budget.

The gentleman from Oklahoma, Mr. Lucas, is recognized for his questions.

Mr. LUCAS. Thank you, Mr. Chairman.

Lieutenant General Stafford, you may not have been there on the first day of NASA, but you've been there in one capacity as an astronaut or a manager or an advisor since the Kennedy Administration.

Lt. Gen. STAFFORD. He was my boss for a brief period of time, too.

Mr. LUCAS. You're a lucky man. I bet he was there, too.

Lt. Gen. STAFFORD. I was.

Mr. LUCAS. So, Lieutenant General Stafford, from your perspective if you could expand for a moment, what are the things that we on the committee should be concerned about? What perils lie out there that we should be prepared to think about?

Lt. Gen. STAFFORD. Mr. Lucas, we talk about human spaceflight. The number one criteria is safety absolutely above all. And what concerns me is that NASA—we've set the criteria. We understand it, but yet at times it's gone away from us like those two accidents

we had on the shuttle, the tragic fire we had early on in Apollo, but then we came back. Then we had Apollo 13, and we learned a lot of things. And we have all of these strict requirements. And if you violate those requirements, it can be a very bad day. That is one thing is my concern is we have safety and we have rigid reinforcement all the way through for that.

Mr. LUCAS. Very good observation, General. Also along that same line, there are opportunities that avail itself, whether it's the Moon or the asteroids or Mars or things a century on down the road, and there's lots of discussion in this day and time amongst members of the committee and the general public about NASA's role versus the growing industry so to speak, how to maintain that balance. Do you have any observations on that?

Lt. Gen. STAFFORD. Well, the volunteer work I do now is the advisory committee for the International Space Station, so we just look at the mess, you know, coming up and there's been some failures we've had. But when I use the word commercial, I go back to my fortunate experience for about 30 years, and I served on 14 boards on the New York Stock Exchange over this period of time, so I think I understand what—

Mr. LUCAS. You have come a long way since Weatherford high school, yes.

Lt. Gen. STAFFORD. Yes, sir. So—thank you, sir. But what is called commercial to me is not really truly commercial. It's probably more subsidized. That's what—Mr. Lucas, what I would say. But in other words, if you have commercial, you plan to make a profit, but where do the funds come from? Are you going to be able to sell this? Now, there's a long-term thing and there might be progress payments, but I don't really see it as pure commercial right now the way it is.

Mr. LUCAS. Thank you, General.

Dr. Schmitt, you have the unique perspective not only of being an astronaut and a scientist, but you've been a part of a legislative body. You have—that other body.

Dr. SCHMITT. The other body, yes.

Mr. LUCAS. And that's a polite way to put it today, that other body. So you've seen the appropriations process from the inside. You've seen the budget process from the inside in the other body. Would you agree that we face certain challenges as a committee trying to make sure that resources are properly allocated to do the things we need to do? I mean, you went through these struggles as a Senator.

Dr. SCHMITT. Yes, no question about it, Congressman. The problem is political diversity. There is a great pressure to deal with many different things for many different constituencies, and I really think, again, that if we're going to focus on the geopolitical issue, we're going to have to truly focus. And everybody has to realize that there may be other ways to get the diversity, but the agency that is charged with going forward with human spaceflight is going to have to focus on that. And I think the House and Senate are going to have to focus and try to resist what has been going on and that's this political diversity that's been asked of the agency.

Mr. LUCAS. Well, Senator, I wholeheartedly agree with you, and I acknowledge we have to make tough decisions. Matter of fact,

when I leave this committee hearing, I'm going to a meeting of the Ag Committee where we're going to discuss what you should be able to do with your food stamps. It should be lively and exciting.

With that, Mr. Chairman, I yield back.

Chairman SMITH. Thank you, Mr. Lucas.

And the gentlewoman from Oregon, Ms. Bonamici, is recognized for her questions.

Ms. BONAMICI. Thank you very much, Mr. Chairman, and Ranking Member Johnson, and to all of our witnesses today. I think this is the only Committee in Congress where the biographical information is longer than the testimony. So I really appreciate all of your expertise and your background.

Lieutenant General Stafford, Russia has been in the news quite a bit lately, and there is much to be concerned about and investigated. But there have been other strained times in our relationship, and the space program has always stood out as a diplomatic success. It is vital that space exploration does not become a political issue between Russia and the United States. So what is your assessment of the current state of the Russian space program? We are, as of today, still relying on Russia for launching our U.S. astronauts to the International Space Station. Do you have any concerns about that or concerns about the reliability or quality of the launch vehicles or Soyuz at this time?

Lt. Gen. STAFFORD. Well, Congresswoman, that's a very good question. And I was fortunate at the height of the Cold War when each country had 6 or 8,000 nuclear weapons aimed at each other we did the Apollo-Soyuz mission. And the Soviets and now the Russians—at times they were difficult as far as the negotiations. However, once they negotiated and signed up to the agreement, they lived up to it. And it worked out very well and set the background for the future shuttle here and the International Space Station.

Now, they have recently had—well, over a period of time I think three progress failures that have gone on that booster. It's slightly different than what we fly with a spacecraft. Now, the—in the first stage of the Soyuz booster, they've flown over 2,000 and it's fairly reliable. It's in the upper stages where they're having the problems. However, the—it's a very rugged vehicle. It's landed in low hills and really mountains at times, something we haven't been able to do, and we can land on water so I—and they have upheld their part of the agreement all the way through. And again, they are very much aware of safety criteria as we are.

Ms. BONAMICI. Terrific. Well, thank you. And I think we can learn from history and what our countries have done in the past and maintained that relationship despite what happens in other spaces.

So, Dr. Stofan, Oregon State University in my home State receives significant funding from NASA. The work they do helps inform important national activities you discuss in your testimony like weather forecasting, ocean monitoring. What are some of the concrete examples of how Earth science missions and research have benefited the American people and our economy?

And then I also want to ask you—I'll ask you both questions at once. What can we do—we as Members of Congress, you as experts in your field—to inspire the next generation, as Dr. Bera was talk-

ing about, other than movies like *Hidden Figures*, which I think is playing a big part right now and inspiring young people? What can we do as communities to inspire young people to keep this mission going?

Dr. STOFAN. Thank you. I think when you look across what NASA is doing, you can pick certainly specific observations, for example, in California the work we've been doing with multiple sensors to look at with our GRACE spacecraft to assess the amount of water we've been pulling out of aquifers in California. We also did a test project over the last couple years where we were working with farmers to develop an app to assess the amount of water, the health of their crops, the amount of water they were using, and it actually got some of the farmers to use about 25 to 35 percent less water on their crops.

So there's a lot of specific examples of this, of NASA working to solve problems, whether it's in agriculture or in water management, where we again have an app that's now in the hands of water managers and farmers to help them assess crop health and control their water usage.

So across the board we've been taking NASA earth science data, which has historically been for the scientific community to do science stuff with and turning it into information that helps people in their everyday lives whether, again, its agriculture or water planning. This is critically important. And NASA has that unique global perspective, that unique vantagepoint of space. We develop the technology, we develop the next-generation instrumentation. And when I say we, I very much mean with our university partners in basically every State in this country. It's the NASA family that's doing all this work and giving the benefits to people in every State in this country.

For that second part, you know, inspiration, Charlie used to say—Charlie Bolden, my boss, would always say, you know, the best STEM outreach NASA ever does is when we launch a rocket into space. When we do great things, that's when we inspire. And believe me, I'm a huge fan of STEM education programs, especially in getting girls and underrepresented groups involved and engaged in STEM.

But the best way we can do that, the best way we can engage that NASA generation is the same way that we did in Apollo. When we have humans walking on Mars, you're going to see a huge spike in Ph.D.'s just like we did after Apollo, the well-known Apollo effect. We do nothing better than when we do great things. And from *The Martian* to *Hidden Figures*, you see the public really engaged in going to Mars. And we need to accomplish that.

Ms. BONAMICI. Thank you. My time is expired. I yield back. Thank you, Mr. Chairman.

Chairman SMITH. Thank you, Ms. Bonamici.

The gentleman from Alabama, Mr. Brooks, is recognized.

Mr. BROOKS. Thank you, Mr. Chairman.

My question is to Lieutenant General Stafford, but please, if any of the other three would like to chime in after his remarks, feel free to do so.

Lieutenant General Stafford, in your written testimony you mentioned that during an 11-month period from 1968 to 1969 the Sat-

urn V rocket flew five times, roughly once every 2 months. This launch frequency is obviously much higher than the early plans for the Space Launch System. Should we worry about the Space Launch System launch frequency, and how will this impact safety and cost?

Lt. Gen. STAFFORD. Thank you, Mr. Brooks. When you have long delays in between, you still have to—it costs money to have the support people there to go. And the better tempo you hit, the cheaper it's going to be—or should I say, sir, the less cost it will be per launch and also probably the safer it will be. And, you know, I think you need more than one every two years, and I don't know the optimum number but you need it where you have a somewhat repetitive, rapid repeatability, and that would definitely enhance safety, it would reduce costs.

Mr. BROOKS. But you testified that you don't know the optimum rate. From that I infer the exact optimum rate, but do you have some kind of judgment or range that you think would be preferable?

Lt. Gen. STAFFORD. Well, Mr. Brooks I would say probably a minimum of two a year, three a year would be desirable, but a minimum would be two a year, sir.

Mr. BROOKS. Would any of the other witnesses like to add any insight?

Dr. SCHMITT. I would agree with that number. I think that two a year keeps the team active, keeps the team on their toes, and that's what I think Lieutenant General Stafford is referring to is that—having a launch every two years or so is certainly not optimum but two launches a year and a program that matches that I think is compatible with what we talked about earlier.

Mr. BROOKS. Mr. Young?

Mr. YOUNG. Yes, first off, your first question was should we worry about it? And the answer is yes, absolutely. When I was Director of Goddard, we managed the Delta rocket at the time. We launched one a month while I was there. When I was President of Martin Marietta, we launched an awful lot of large Titan vehicles.

I think there's one thing that everybody in the launch vehicle business knows. The higher the launch rate, the higher the probability of success. And when you talk about launching a sophisticated rocket once every three years or once every two years, I think the answer in my view is that's not acceptable. And so where does the cutoff come? I don't exactly know. If you get to what—both comments that Tom and Jack made of two a year, two a year is not an unreasonable number. If you get much less than that, you really need to study the problem very hard to see if you have special techniques you can put in place to hopefully bridge the gap of not launching frequently. But the largest—I'm a big supporter of SLS, but the thing I would be most worried about is the infrequency of launches.

Dr. STOFAN. If I could also just quickly comment?

Mr. BROOKS. Please do.

Dr. STOFAN. The SLS rocket has the time to get to the outer solar system, so if we're pursuing this question of going out to those ocean worlds of the outer solar system, the SLS is a great

asset. So the scientific community is always ready to make use of those extra launches.

Mr. BROOKS. In the limited time I have left this is a general question for whoever wishes to take a shot at it. Is there a market for heavy-lift beyond NASA? Is it possible to design effective exploration architectures that make use of both the SLS, as well as the commercial heavy-lift vehicles currently under development? And what are the advantages or disadvantages?

Dr. SCHMITT. Well, I'll take a crack at that. I think there is. I about ten years ago published a book where I thought the private investors might be interested in funding both a heavy-lift launch vehicle and activities on the Moon in pursuit of lunar resources, particularly fusion fuel helium-3. Now, with the SLS that partnership I think is even more viable with the government because the private sector can now—or the investor sector can concentrate on the resource side of things rather than on the launch vehicles. So if you put together that kind of a partnership for lunar development, then I think, yes, it'll be a tremendous need for launches on the order of two a year if not more.

Mr. BROOKS. Thank you, Mr. Chairman. I see my time has expired. I yield back.

Chairman SMITH. Thank you, Mr. Brooks.

And the gentleman from California, Mr. Bera, is recognized.

Mr. BERA. Thank you, Mr. Chairman.

Yes, I kind of think about and reflect on my opening comments and think about the success of the Gemini and Apollo programs. Let me just read President Kennedy's quote. "We choose to go to the Moon. We choose to go to the Moon in this decade and do the other things not because they are easy but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone and one we intend to win, and the others, too."

And in laying down that challenge to us as a nation, he was also touching on the importance of strong science research programs, the importance of federal funding, the importance of investing in the next generation so that we would have that next generation of scientists. Now, I wasn't born when he gave that speech, but I'm a direct beneficiary of the challenge that was laid out there, and I think all of us in the country are.

Would you say part of the success was that there was a direct challenge in a specific timeline that wasn't about one Administration to the next because achieving the goals spanned Administrations but there was a clear goal that was set out? Lieutenant General Stafford?

Lt. Gen. STAFFORD. That's a very good point, sir, and I do think we need specific goals and we need stability. But one thing I'd recommend to the Committee—and I said this before—that I saw that was so effective was called the National Space Council. And it was put into law by the majority leader after Sputnik at the same time DARPA was formed and NASA was formed. That was by Majority Leader Lyndon Johnson called the National Space Council. President Eisenhower decided not to activate it. For some reason he thought it would take away some power, but as soon as President

Kennedy was elected, he put Vice President Johnson in charge of the National Space Council.

And believe me, sir, I was new to NASA but it flat moved, and then after him, Hubert Humphrey, and it continued on until President Nixon reorganized the White House in 1973 and it went away. The next time it was reactivated was when President Bush Senior said let's go back to the Moon and on to Mars and put Vice President Quayle in charge of the National Space Council. And that way it was focused and you didn't have people like lower-level OMB people taking pieces out here or there or think that they help to recognize—it focuses it.

Mr. BERA. Absolutely. So having a specific goal, having a specific time frame that doesn't change from Administration to Administration—

Lt. Gen. STAFFORD. That's right.

Mr. BERA. You know, my colleague from Colorado gave me this sticker. It says "2033: We can do this." you know? And—right, we can do this. And, Mr. Young, you touched on it.

Mr. YOUNG. Yes, if I could just add a little bit to your question. I think having it—absolutely the answer is yes. I was a young engineer at that time working for NASA. There was no confusion by me or my colleagues as to what our objective was, what we were trying to accomplish. And anything that was not critical to the success of that accomplishment, we just didn't do. In other words, we were focused on that goal and that objective. And I mean I remember that as rigorously as I can remember anything. And unfortunately, that's not where we are today.

Mr. BERA. And I think if we want to accomplish what we want to accomplish, we have to get back to that and folks can sit here and say, well, we're in political turmoil as a nation, we're divided. Look back at the 1960s. I don't think it was a time of political stability, yet we had national pride, we had a national goal, and we went out to accomplish it. And in some ways that could be what brings us together as a nation as well.

Dr. Schmitt?

Dr. SCHMITT. Congressman Bera, I totally agree with you. That's why in my oral testimony and written testimony I indicated milestones. I think you need those. You need to commit to those. And one essential ingredient is that Congress and the OMB and the White House have to be willing to provide management reserve of funding. You cannot make milestones in complicated programs unless you have a management reserve. Now, do you need 100 percent like we had an Apollo? No, we're much smarter than we were. But I think generally a 30 percent management reserve until you get to critical design review on various systems is absolutely essential to keep on schedule.

Mr. BERA. Right. And, Dr. Stofan, you've already laid out what those milestones are to go into orbit around Mars in 2032. Was that the goal? Well, let's set that out there. Let's put it out there and let's not continually change course. Let's actually dedicate the resources, the person power and inspire that next generation. So I notice I'm out of time but thank you guys for everything that you've done for our country.

Chairman SMITH. And thank you, Mr. Bera.

And the gentleman from Illinois, Mr. Hultgren, is recognized for his questions.

Mr. HULTGREN. Thank you, Chairman. Thank you all so much for being here. You truly are our heroes. We're grateful for each one of you, what you've done and continue to do, so thank you so much for that. You're fine.

But I have some questions for you, and this is an inspiring time but also any time I get a chance to talk about NASA is inspiring to me. And I think it's so important for us to be starting this new Congress and this great Committee, which I'm so honored to serve on with Chairman Smith and my colleagues, but it is so important for us for so many reasons. But I think maybe one of the most important reasons is how NASA, throughout our history, continues to be such a place that inspires the next generation, next generation of astronauts, of scientists, of physicists, of people engaged in that discovery, that idea that has always been such a key part of who we are as a nation.

And so I have been really excited. One of the things that we've been doing in my district recently is we reached out—I represent seven counties but we reached out to high school students and we started a STEM scholar program where I meet with 19 of our STEM scholars from around the 14th Congressional District in Illinois. We meet monthly going to different STEM facilities, whether it's a research facility or a university or other things to be able to learn from them.

I had a chance to be with some good friends of mine, the Cain brothers. Cain Tubular has worked very closely with NASA in exhaust systems for our rocket engines and the students just loved it. We had a person from NASA come in and speak to them as well. So, so good for us to learn together, be inspired, but also to hear from them what's worked for them, what teacher inspired them, what program inspired them.

So I asked them if they had any questions for NASA, for astronauts, for scientists who have been engaged in important work, so I reached out to them and I'm going to use the remainder of my couple of minutes to ask some of the questions that my STEM scholars had if that's all right.

First, Claire, who is just a brilliant young student, has been involved in FIRST Robotics as an engineer, drive coach, and outreach coordinator for her team "Got Robot." But Claire asks how does NASA—what has NASA done in the past and what does it plan to do to continue to encourage students to pursue careers in STEM to become that next generation of brilliant scientists and astronauts? And is there a way that NASA can help build curriculum or lessons that could reach more students to be able to do that? And I'd just open that up. What do you think NASA is doing or should do to inspire young people, that next generation of astronauts and scientists?

Dr. STOFAN. You know, through our NASA education programs, we have a lot of programs that are focused on kids in STEM and how to get kids engaged in STEM. And I think it's a constant challenge on how do we make sure those programs are really producing good results. You know, how can we make sure that they're effective? And I think over the last several years we've really taken a

hard look at our programs and tried to say, where are we actually moving the needle on this? It's a huge source of frustration when we still don't see girls and underrepresented groups getting into STEM.

One of the things we do that I think is effective is we partner with FIRST Robotics—

Mr. HULTGREN. Good.

Dr. STOFAN. —for example, and I think—

Mr. HULTGREN. It's a great, great program.

Dr. STOFAN. —it's a great program.

Mr. HULTGREN. Me, too. Good. I think to just continuing to tell your story, and we had the chance last Congress to be able to connect with astronauts up on the International Space Station. And I see all the time as I see the NASA channel, oftentimes, our astronauts are connecting with students and school groups and how important that is.

Let me ask another quick question. Andrew, another one of my STEM scholars from St. Charles, Illinois, another brilliant young man who is very interested in cyber issues, cybersecurity, he's a CyberPatriot and also very active in the Civil Air Patrol and Air Force Association. But he had a three-part question if I can ask my last one. As we continuously are moving forward in an interconnected world on the digital level with a greater need for computing power for our future space travel and advancements, we know that our adversaries will take advantage of every aspect of our nation's vulnerabilities. How can someone like me—this is Andrew asking—who is currently involved in cybersecurity education and competition for the past three years contribute to the current and future space travel and advancement? Also, do you think cybersecurity plays a major role in NASA? Lastly, what is the current demand for cybersecurity jobs in NASA?

Dr. SCHMITT. Well, it sounds like that young man is doing everything he needs to do to get ready—

Mr. HULTGREN. I'm just trying to grab onto his coattails. He's amazing.

Dr. SCHMITT. —and to answer his own question. I have some responsibilities in Orbital ATK for cybersecurity, and it is an extraordinarily complicated issue. It has to be addressed by the government as well as by corporations, and it's just going to be something that's with us continuously, and we're just going to have to start to get smarter and smarter.

One of the things that has interested me recently is to try to get security built into processors. And the Draper Laboratory, with which I'm also associated, has developed some means to do that so that you continue to use the firewalls and the whitelisting and other aspects of cybersecurity, but you build into the processor that kind of security. And I think it's an intriguing idea, and it's something that Andrew may want to look into.

Mr. HULTGREN. Good. Thank you. My time is expired. We have some other questions that I hope we can maybe give to you all. Some of my other STEM scholars had questions if we can follow up.

One last word, Chairman. I just want to say thank you to Lieutenant General Stafford, all of you, so grateful, but, Lieutenant

General Stafford, I really appreciate all that you have done and mean to us and really appreciated your words last night talking about Gene Cernan and your work with him. We miss him but we're just so grateful to you and all that you mean to us as a nation but also to our space program. But all of you, thank you so much. With that, I yield back.

Chairman SMITH. Thank you, Mr. Hultgren.

And the gentlewoman from Connecticut, Ms. Esty, is recognized for her questions.

Ms. ESTY. Thank you, Mr. Chairman. And again, many thanks to the Ranking Member, to the Chairman, and really to our distinguished panelists today.

We have a lot of STEM activities in my District and had the excitement of having a direct link from the International Space Station with 3,000 students watching from Waterbury, Connecticut, seeing a graduate from their high school talk to his former calculus teacher. And I will tell you, there is very little—you've all mentioned the importance of students really seeing that.

So the challenge we face here is we've got a lot of different objectives for NASA on the table right now and not enough money and not enough time to pursue them all in a sequence that inspires. So if you can talk a little bit more, how do we establish benchmarks? And if you are willing to say what would you lop off or put down to lower priorities if we really think that manned exploration is vital, which many of you have said, if you have to triage—I think we'd rather plus up here but we may not have that option. And I see Mr. Young is ready to go with the triage question. Thank you.

Mr. YOUNG. It's a great question and I actually think the crucial question. My personal belief is that the priority for human spaceflight should be exploration, boots on the ground, either the Moon or Mars. My choice is Mars. To do that we've got—as you say, we've got to not do some other important things. My personal belief that I mentioned is commercializing low-Earth orbit, I think NASA should not be in that business except for providing technological support. So that would be my item that I would cross off.

International Space Station is the more difficult of the questions. I personally—and there's no way that we can have a credible exploration program and a credible low-Earth orbit space station program at the current budget in my view. So I would prioritize those things that are necessary to support humans to Mars. I would accomplish those and I would transition if possible it to the commercial world as soon as I could.

The other thing that's going to consume a lot of resources is the decade-worth of effort in cislunar space. I personally believe there's a lot of things that need to be done in cislunar space to support the Mars program, but I wouldn't establish a cislunar space program on its own. I would establish a Mars program, and then from the Mars program, I would figure out what do I need to do in cislunar space to get to Mars.

So I think a human-to-Mars mission will stretch us almost to our limits but I think is achievable. But to do it we've kind of got to do just what you said. We've got to prioritize. That would be my personal priority. The country could decide it's another priority. You know, maybe commercializing low-Earth orbit is the right pri-

ority. If that's true, get the rest of the stuff out of the way, but it's not what I would personally do.

Ms. ESTY. I see at least two other nodding heads on prioritizing Mars. Does everyone have an agreement around that? Because if this is—we are going to have to make some very difficult decisions if we are going to achieve any of these things in a time frame that makes any sense. And I think we—as our colleague Dr. Bera underscored, you do need focus, and that does help—public support is enhanced when there are timelines and there are benchmarks and people can see that progress. That galvanizes support, which makes it easier for us to achieve not just that goal but other ones as well.

Others who would like to chime in?

Dr. SCHMITT. Well, I think Tom Young has articulated it very well. I have already made the leap that the Moon is extraordinarily important to get to Mars, but I think anything you do in this so-called cislunar space has to be with that in mind. It doesn't mean other things won't happen as a result scientifically and operationally, but you really do need that experience. A generation or two needs the experience that we used to have as a result of Apollo if you're going to go to Mars successfully.

Dr. STOFAN. Yes, I think it's really critical that we do say focused. And I would call the Committee's attention to the work that Mr. Lightfoot has been doing over the last several years to really look inside NASA and say, you know, what are we duplicating at our various NASA centers? How do we focus? Over the last, I would argue, at least ten years, NASA has been carrying too many potential futures, too many potential paths. Robert has already begun the work to try to say we have one path; we're going to Mars; let's narrow this down. We've started on that path. The guidance of this Committee, of this Congress, would help solidify that.

Ms. ESTY. Thank you. That's all very helpful for us because, again, we want to be helpful in achieving these missions, and if there are too many missions, none will be achieved. And that is a great loss not to just this country but really to the future of the human species. So we would like to be helpful in this process. Thanks—thank you very much. And it looks like the General also has—

Lt. Gen. STAFFORD. Yes, I'd like to point out one thing to the Committee, particularly the new members. In physics when we talk about Mars, you know, it's in a 687-day orbit where we're in a 365-1/4. It's inclined 1.9 degrees. You put all this together, which APL did this for us in a study. And you have—you can only launch from Mars every 26 months, and you have about a 60-day window. But also there's a sinusoid, an energy per kilogram—or pound if you want to put it that way—that's required and we're right down—there's a 15-year sinusoid, and we're right down near the minimum now, 2016, '17, '18. Then it starts back up. By the time you get to, say, 2024, '25, you're up near the peak so it's going to take—you can only put a little payload there. Then it starts down. And so 15 years from now, 2031, '32, '33, you're down in this thing so you can set a target. But that is that one thing when you talk Mars that you have to remember all the way, that 15-year sinusoid.

Dr. SCHMITT. I'm going to beat that with fusion propulsion, Tom. You won't have to launch every 26 months.

Chairman SMITH. Thank you, Ms. Esty.

And the gentleman from Oklahoma, Mr. Bridenstine, is recognized.

Mr. BRIDENSTINE. Thank you, Mr. Chairman. Serving on this Committee is a high privilege, especially because we have the opportunity to discuss things like this with this amazing panel. So thank you all for being here.

Before I get started on Moon/Mars, I think that's an important discussion, but I want to say the first time I had a conversation with the Lieutenant General Stafford I was running the Tulsa Air and Space Museum. I had just left the United States Navy as a pilot and here I am at this museum. We made an effort, Mr. Chairman, to get a space shuttle in the city of Tulsa, and we had a long history with the shuttle. We built the bay doors on the space shuttle. We had built the shuttle carrier aircraft, the 747 that carries the shuttle on its back was modified in Tulsa. We built the big devices that picked the shuttle up and make it vertical for the launch deck. NASA said you need a 10,000-foot runway to have a shuttle on display at your museum. You need a museum dedicated to education.

So we made this effort to go after a shuttle. And I was pretty new at the museum at the time and I get this call, and my staffer comes in and says Lieutenant General Tom Stafford is on the phone for you. And I said yes, and the Easter Bunny is on line two, right? And of course Lieutenant General Tom Stafford was on the Board of Directors for the National Museum of the U.S. Air Force and he wanted to let me know that the U.S. Air Force Museum was going to be getting a shuttle and not the Tulsa Air and Space Museum.

I'm sad to report, sir, that neither one of us got a space shuttle, but it was a great conversation and I appreciate you being from Oklahoma. If none of you have—if you've ever been to Oklahoma, if you ever get a chance to go to Oklahoma, I highly recommend visiting the Tom Stafford Museum. You're doing a lot to inspire the young, you know, generation in Oklahoma, and thank you for all your great work there.

I want to talk for a second about this Moon/Mars thing because I think it's important. While we all want to go to the Moon, and certainly with my friend from Colorado, Mr. Perlmutter, 2033, great goal; I think it ought to be 2032. I think most Republicans agree with the 2032 number. But while that's important, I've heard Dr. Schmitt and Lieutenant General Stafford talk about the geopolitical issues here, the fact that there is a soft power element here.

We know what China is doing. They're launching taikonauts on Chinese rockets to their own Chinese space station. Not too long ago they put an orbiter around the Moon to map the Moon. After a year of mapping the Moon they launched it deeper into space to the L2 point 60,000 kilometers on the back side of the Moon where it shut down and just hovered for a period of 8 months before repowering and flying into deep space in formation with an aster-

oid. That is a massive achievement and accomplishment that is astonishing.

We also know that the Chinese have launched direct-ascent anti-satellite weapons, one that in fact shot down one of their own satellites, creating a space debris field of 3,000 pieces.

We also know that they are currently testing antisatellite weapons all the way out to geostationary orbit where our most important communication satellites, AEHF or nuclear command and control communications, WGS. For those of us that are tactical operators, we depend on WGS and of course all of our space-based infrared systems to detect missile launch systems all in that very important orbital regime out there in geostationary orbit.

The Chinese have demonstrated if not the desire, they have at least demonstrated the capacity to attack that geostationary orbit from above, and that is a critical concern that everybody on this Committee should be taking note of because of the situational awareness limitations that we have in deep space.

So when we think about the Moon and when we think about Mars, we all want to get to Mars in 2033. I think that's a great objective. I will also say that cislunar is critically important for the geopolitical position of the United States of America and the Mars is the horizon goal. It's critical. We need to get there. The Moon I believe is necessary.

And, Dr. Schmitt, I'm going to turn it over to you for a second because you've talked about how it's possible that the U.S. Government could in essence provide transportation to not only lunar orbit but to the lunar surface and have the private sector invest in developing not only the Moon but the capacity for cislunar, which is a geopolitical concern right now for the United States. Can you address how we could leverage commercial in that realm?

Dr. SCHMITT. Well, I've been convinced for a long time, Congressman, that ultimately the private sector, as Tom as pointed out, can truly commercialize for-profit, exploit the resources of the lunar surface, the part of the lunar surface called the regolith, which is a debris layer that covers the Moon that's several meters thick. That contains hydrogen, oxygen, nitrogen, carbon, and helium, and particularly this fusion fuel called helium-3.

So the only basis I'm aware of for a truly commercial operation is in lunar resources and both for use in space and for use here on Earth. And if the government as it is right now is moving towards developing heavy-lift launch vehicles, then that opens the door I think for this partnership to really be a viable one. And I talk to people about it all the time obviously, and we'll just have to wait and see whether the investor community or the energy community step up and realize that this long-term potential is there.

Mr. BRIDENSTINE. Thank you. I yield back.

Chairman SMITH. Thank you, Mr. Bridenstine.

And the gentleman from Virginia, Mr. Beyer, is recognized for his questions.

Mr. BEYER. Thank you, Mr. Chairman. And, Chairman, thank you for having this hearing. It's fascinating. Thank all of you for being here.

Dr. Stofan, when Lieutenant General Stafford in his testimony he—let me quote it. He said that basically, the next flagship

science mission will be the James Webb Space Telescope initiated in the Bush Administration with nothing comparable initiated during the eight years of the Obama Administration, and goes on to suggest a lack of leadership during these last eight years. You were there as the Chief Scientist. How would you react to that?

Dr. STOFAN. Well, obviously, I don't agree with that. We initiated the Mars 2020 mission. We'll be setting the stage to return samples from Mars in the mid-2020s, which I didn't even get into. It's critical to bring those samples back in the 2020s, which will allow us to develop our entry, descent, landing ascent, and return-to-Earth capabilities.

So Mars 2020, WFIRST, our next telescope after James Webb, was initiated under this Administration, a mission to Europa initiated under this Administration, this past Administration, a revolution in small satellite technology that's underpinning the huge revolution. We just saw all these planet satellites launched a few days ago. All that technology has been worked on at NASA over the eight years. It's transformed through a lot of our programs, our small satellite, our lower-cost options in astrophysics, heliophysics, planetary earth science. We've made incredible progress over the eight years, building on the long bipartisan history of NASA.

And so I don't think it's, oh, we accomplished a lot in the past; we've done nothing over the eight years. I think NASA has continued to execute the Decadal Surveys. We've made strong progress. We will hopefully continue to make strong progress with this Committee's support.

Mr. BEYER. Thank you. Dr. Stofan, one of the—the conversations that we have on this Committee is the role of Earth sciences in NASA's budget. But as I understand now where it's about \$1.9 billion out of the \$19.5 billion. And I know my—the Chairman, my friend, has talked about the rebalancing of the NASA portfolio, and so we often are concerned that this means the disappearance of the Earth sciences budget as part of that, redirecting into deep space, for example. How would—what would happen if NASA's Earth science budget were eliminated?

Dr. STOFAN. Well, first of all, I would point out that the earth science budget has actually been fairly flat over about the last 20-plus years. In fact, if you look back at around 2000 it was about \$1.4 billion, which, if you put that in today's dollars, we are actually lower. So the earth science budget has actually not grown. It's slightly shrunk.

Again, NASA has the unique vantagepoint of space. We build NOAA's weather satellites, the GOES-R, which has been returning amazing images of this planet. That satellite was built by NASA. We do have four other agencies. We built Landsat, which is critical to farmers, to urban planners all around the world. We are studying the global water cycle. We're developing that next generation of instruments. NASA's earth science program is critically important.

And I would also remind people that the technologies that come out of the investments in the earth science program spawn new industries, that downstream application of earth science data collected by NASA and made open to the public have created new companies—Orbital Insight, DigitalGlobe. I can, you know, sit here

and name companies that get downstream value, create jobs all across this country. The earth science program is an investment in this country and it returns benefits to all of us every day.

Mr. BEYER. Thank you. And my friend the Chairman doesn't want me to exaggerate, the complete elimination but rather rebalancing. Okay.

Dr. Schmitt, as—wonderful to have the geologists here, but I know you're deeply involved in fusion power, too. And you talked about fusion power for this. Do you—in your work do you see any relevance for fusion power for power here on Earth?

Dr. SCHMITT. Well, I certainly do. I think the—having done an economic analysis of this some years ago, I think the potential for helium-3 fusion power on Earth is very, very great. Now, it's not something that's going to happen overnight and it's—it takes a long view of things before you start to make a profit on it. But nevertheless, the resources there on the Moon, the technology is advancing here on Earth to use helium-3 in fusion devices. Most of that has been done with private funding so far. You may have recently seen a press release from Tri Alpha, a Paul Allen-funded operation where they are working on boron—what's called P-boron-11, but the technology base is equally compatible for helium—lunar helium-3 fusion power.

The nice thing about helium-3 fusion power is that you don't produce neutrons. Neutrons are bad actors. They create the radioactive waste that we worry about. And certainly DT, tritium-deuterium fusion device is going to create a great deal of waste, and that's often not talked about when we talk—when we think about these—the ITER project in Europe and so forth.

But helium-3 fusion produces protons, which can be directly converted to electricity at very—at high efficiency, as well as without the difficulty of waste production. So I think in the long term if you want an environmentally—relatively environmentally benign energy source for the very long term, then this something that ultimately I think we're going to look very closely at.

Mr. BEYER. Great. Thank you very much. Mr. Chair, I yield back.

Chairman SMITH. Thank you, Mr. Beyer.

The gentleman from Texas, Mr. Weber, is recognized.

Mr. WEBER. Thank you, Mr. Chairman. Dr. Schmitt, I think it was you early on in your comments who said you think one piece of advice you would give NASA was to resist political diversity for the agency. Would you elaborate on that?

Dr. SCHMITT. It's just that the kind of things that we've talked about in terms of focusing, many of the things that NASA does are really within the purview of other agencies, and I think that that ought to be examined very closely by this Committee, which has the responsibility for several agencies, not just NASA. And that just because you start to focus on Mars and deep space doesn't mean that these other programs have to go away. They can be, I think, taken under the umbrella of other agencies, and that ought to be looked at very carefully.

Now, does NASA stay in the business of actually providing technological assistance such as they do for NOAA? That's a question that you'll just have to discuss and try to answer. But other agen-

cies do have the same responsibilities in the areas where NASA has been diversifying over the last several decades.

Mr. WEBER. Okay. There was a little bit of the conversation I think that the Ranking Member, Chair just alluded to that it seems like there would be a rebalancing of the budget, and perhaps that's part of what you're taking on in the budget process.

I cannot overstate what I believe is the importance of NASA. And, Lieutenant General Stafford, I don't want to get into your bailiwick but—not having had the privilege of serving in the military you know, they say that whatever force occupies the high ground has the upper hand, and folks, there is no higher ground than space.

And to my good friend from Oklahoma, Congressman Bridenstine's comments about the Chinese able to shoot down satellites, that ought to be pretty alarming and a wakeup call for us all.

You actually said in an exchange with Suzanne Bonamici earlier—or the comments were that she didn't want space exploration to become an issue between the United States and Russia. Well, that was before Jim had made his comments about China. Do you think that's a prudent outlook to not be on guard and to really want that competitive edge and that military edge? Do you think United States literally ought to be going after that kind of edge?

Lt. Gen. STAFFORD. Well, Congressman, to me the United States—in this case it would I would think the Air Force's responsibility—it could be Army and the ballistic missile defense, but we need to be the leaders in the world. And we need to have, under the DOD, funds for that.

Mr. WEBER. So you would say that the leaders in the world not just because of STEM and the other—the pride that Dr. Ami Bera talked about but other issues but for national security?

Lt. Gen. STAFFORD. Right, for national security, absolutely, what Congressman Bridenstine has mentioned there, that we need to be right there out in front of everything, on top of everything.

Dr. SCHMITT. We—Congressman, if I may just add to those remarks, we tend to forget that Apollo was a creature of the Cold War. It really was.

Mr. WEBER. Oh, I don't forget.

Dr. SCHMITT. And we gained a great deal of science, a great deal of technology, and many, many other things from that effort. But the stimulus, the impetus was the Cold War and a very important part of it—

Mr. WEBER. Right.

Dr. SCHMITT. —I would say. So that has to be kept in mind. And as far as I'm concerned, with Congressman Bridenstine's comments, we are very close to being in a Cold War today and need that kind of—

Mr. WEBER. Right.

Dr. SCHMITT. —impetus and with a milestone focus as was discussed earlier.

Mr. WEBER. Well, thank you for saying that. And the gentlelady from Oregon is not here, but I think one of the comments she made was that she didn't want to see this become an issue between the United States and Russia, but I think when you're dealing with the

Russians giving us a ride, to the space station, which to me is an absolute travesty, I think we have to differentiate between the Russian space agency—and y'all would know that better than I would—and the Russian military.

But I would tell you, not knowing any more about that differentiation or either of those agencies than I know, I would have to believe that either one—they would sell us down the river in a heartbeat if it was to their advantage militarily. Would y'all agree with that?

Dr. SCHMITT. I would.

Lt. Gen. STAFFORD. Well, we have to look at it in certain ways. The arrangements with Russia is like a stovepipe. We deal with the Russian space agency, but they have lots of other responsibilities besides what we call, quote, "civil space." And they have lived up to their agreements on that, but they have other agreements, too. They have other things that they support—

Mr. WEBER. Okay.

Lt. Gen. STAFFORD. —where NASA is primarily all civil. And had we continued on the Constellation program, we'd have had American astronauts flying on American rockets in spacecraft in late 2013 or early '14.

Mr. WEBER. Right. Well, thank you for saying that.

Mr. Chairman, I yield back.

Chairman SMITH. Thank you, Mr. Weber.

And the gentleman from Colorado, Mr. Perlmutter, is recognized.

Mr. PERLMUTTER. Thank you, Mr. Chair. First, I'll start with us. We start them young in Colorado. Got the outfit at the Air and Space Museum. Finn Henderson, 4 months old.

Chairman SMITH. Any relation?

Mr. PERLMUTTER. Yes, grandson.

Chairman SMITH. Grandson. Okay.

Mr. PERLMUTTER. Twenty thirty-three, and so, General, I want to talk to you about this and to the entire panel. And I thank you all very much for your testimony today and for your service. And, Senator, I'm going to get to you because we're going to talk about budgets for a second.

But you mentioned sort of the orbital mechanics of all of this, and we had a panel about this time last year of some NASA agency execs, and I expressed to them my disappointment that we hadn't gotten to Mars by now, you know, Star Trek, Star Wars, on the Moon 40 years ago-plus, and why aren't we there? And they said, well, because of fits and starts between Administrations and Congresses. And I said if you had the revenue, if you had the support, steady, sufficient revenues, what's the earliest we could get to Mars? And I was hoping they'd say 2024 and then they kind of went through the two-year cycles that you just talked about and they said 2033 if they had steady, sufficient support.

But that's the \$64 question because it hasn't—it's been kind of fits and starts for all of you. And I, as a legislator, apologize for that because we haven't given you the steady support. And to your point, Mr. Young, you know, it's a mixture of things, the agency's expertise, the private sector's ability to really bring forces and potentially the international community as well.

So it's a responsibility. I mean we find more common ground on this Committee than any of the other committees I've served on in this Congress. And this area especially, space exploration, is the place where I think we really do all have a common interest and want to see us move forward. And it might be a different thing for each of us, what floats our boat, whether it's a national security question or a science and pride question, but whatever it is, maybe we are at the confluence of something big here.

And the reason I'm looking at you, Senator, is the revenues are a hard thing but they're not impossible. We came up with \$800 billion over a weekend to save the banks in 2008. It was a Republican Administration and a Democratic Congress. If we can't—and the number that was given to us was about \$200 billion, maybe 250 over 17 years to get to Mars and, you know, different kinds of ways to do it. I'm a lawyer. I'm not going to say other than I'd like to see this result and let you scientists and engineers tell us how to put the pieces in place. So I'd just like your reaction to that.

Dr. SCHMITT. I think you've hit on a very important point and that rather than thinking in terms of what is the total cost, you need to think in terms of what is a reasonable annual cost of going forward. I think that's what happened to the initiative in the Bush 41 Administration is that it got tarred with a total cost when you can't operate that way. You've got to operate on an annual basis, as you've indicated, and we need to decide what that is. What is a reasonable number in order to make the milestones?

Now, I think 2033 is probably doable. I did not have it on my list of milestones primarily because I'm still not sure that we're going to give NASA the management tools to make that happen.

Mr. PERLMUTTER. Well, and—

Dr. SCHMITT. And this is not the NASA that I—that was managing things when Tom and I were flying in Apollo.

Mr. PERLMUTTER. So let me talk to about that. Let's say, you know—and you know from being a legislator and the diversity of interests around this place how difficult it may be for all of us to come together to have a 17-year plan. Sometimes we can't plan 17 minutes, but if we're able to do that, I'm assuming—and I look to you, Mr. Young, and to you, Dr. Stofan, and, General, to you for your comment—can NASA, together with its private sector contractors, find the management tools to do it? Or is that an impossibility?

Dr. STOFAN. You know, I've spent the last three years visiting every NASA center around this country talking with our private space contractors. The people at NASA are totally capable of doing this. They are chomping at the bit. They need clear direction, they need focus, and they need budgetary support. The people are there; the expertise is there. They're waiting and they're eager to get started on this.

Mr. YOUNG. You know, I think Ellen said it very well. I agree with that. I mean, I think it clearly can be done but it takes some bold leadership, you know, to make it happen. I must share with you—you're talking about dates and some of these dates are mind-boggling to me. You know, we were talking about earlier Kennedy's thing. I think from Kennedy's statement to humans on the Moon was eight years. I remember the first large space project I worked

on as a very junior engineer was the original lunar orbiter where we took the photographs and found the landing sites for Jack and—

Dr. SCHMITT. It was a wonderful program, Tom.

Mr. YOUNG. That program from start until we were in orbit by the Moon was 27 months. And by the way, we were criticized because the commitment was 24 months.

So we obviously have allowed—which I think is what Jack was trying to say—we've allowed an enormous amount of non-value-added work to creep into our execution of programs and that's something that—you know, that we should try to eliminate them as we can. But I think Ellen said it well. I think the people who will do this job are chomping at the bit for the leaders to just unbridle them and let them go.

Mr. PERLMUTTER. Thank you. General?

Lt. Gen. STAFFORD. Well, the one word that sticks in my mind, Congressman, is that this Committee was really the epitome of back in 2010 is the word courage. And this Committee and its corresponding committee in the other body put forth their courage right in front of what the Administration did and canceled Constellation and started the SLS and Orion.

But when you said why weren't we there in 2016, well, we did the study for President Bush 41 and Vice President Quayle at his joint press conference. Our target for Mars was 2016, sir, 2016.

Mr. PERLMUTTER. Well, we've got to get on our horse here and get it done for you. Thank you.

Lt. Gen. STAFFORD. And one thing about it, again, when I recommend the National Space Council so you have somebody with horsepower at the top. It doesn't take any big bureaucracy. Four or five people is all you need in the National Space Council and take it and drive it so you don't have these detractors.

Chairman SMITH. Thank you, Mr. Perlmutter.

The gentleman from California, Mr. Knight, is recognized.

Mr. KNIGHT. Thank you, Mr. Chair.

I'm going to talk about a completely different subject. I know everyone wants to talk about Mars and the Moon and that's great and they're laudable goals, but you can't get to space until you go through the big A, so I'll be talking about the big A. Aeronautics is now about \$700 million I noticed in Dr. Stofan's comments. I read through them and I appreciate her bringing up the X-Plane program and bringing up all the things that we can do.

Lieutenant General Stafford, I will go with you first. We now have a new aviation horizons effort where we have many X-Plane programs that are coming online. The X-57 is the new designation. But the big one that I'd like to talk about is the low boom supersonic demonstrator because we've been flying across this country at .8 Mach for as long as we have flown across this country. And I would hate for my children who are now in their early 20s to be my age someday and say hey, we're still flying across this country at .8 Mach.

And I think that that would be one of the great achievements that we could do, that NASA could do to prove this, to lower the supersonic boom down to the 65 decibel or lower so that we could remove this archaic 1973 FAA law and really do something so we

could travel across this country at 1.8, 1.9. And think of what the economic boom that would be that people could get to their destination 2 hours quicker that are going across the country. So just your opinion of that, Lieutenant General?

Lt. Gen. STAFFORD. Well, Congressman Knight, I think you have made a very valid point in particular not only across the country but across the ocean.

Mr. KNIGHT. Sure.

Lt. Gen. STAFFORD. And I've been fortunate to fly the Concorde many times, so I think you're right on.

I'd like to remind the Committee that Congressman Knight's father was a classmate of mine in Air Force test pilot school, and he flew the X-15 and he set a couple of world records that still stand so we're very proud of your father—

Mr. KNIGHT. Thank you.

Lt. Gen. STAFFORD. —Colonel Pete Knight. But your X program I think is very valid, sir.

Mr. KNIGHT. Thank you. And Dr. Stofan, if you have any comments on that.

Dr. STOFAN. I think NASA's aeronautics program, as I said in my submitted remarks, is really critical. Obviously the aviation industry is a hundreds-of-billions-of-dollars industry here in the United States, and the fundamental research that NASA does from looking at all of the technologies that that we help to develop that are in the new—latest Boeing aircraft, we really underpin a lot of the developments in the U.S. aviation industry.

And so from the low boom demonstrator to the X-Plane program, the investments that NASA makes in aeronautics are really critical, and I think they should be supported by this committee going forward.

I would point out we're also doing work in green fuels, which is critical because when you fly planes at supersonic altitudes you're putting greenhouse gases into a place in the atmosphere where they reside for a long time. So NASA also is doing a clean fuels program along with the low boom demonstrator. Both of those are critical for allowing supersonic air transport.

Mr. KNIGHT. Absolutely. And I wanted to bring up just another point. I know that Mars and the Moon are the big goals, they are, and I think that the way that we get to those big goals—and I think Dr. Schmitt said it—that you've got to lay out the goal and you've got to say that we are going to do this by 2032 or we are going to set this. And we've got to fund it every year. That is Congress' mission, to fund it every year.

The smart people will figure it out. NASA is way ahead, and I know that they can accomplish these goals, but if we don't fund it every year and if we don't have a mission through Administrations, we will not get there. It will be a start and stop just like we have done with many different programs. And I bring up hypersonics that we have worked on for the last 50 years in start-and-stop issues. Our last start and stop was the X-43 and the X-51, and we have done great data-collecting of those periods of time. But now we are seeing other countries take our data, steal it, and then jump forward and then maybe fund. So now we are seeing other coun-

tries maybe establish a weapon that would hurt us at 3,800 miles an hour.

And so those are the things that NASA has also got to be very cognizant of when we do these budgets is that the big items are the big items, but there are also many, many items that accomplish missions. And my time is—

Dr. SCHMITT. Congressman, if I could—

Mr. KNIGHT. Yes, sir.

Dr. SCHMITT. —I have suggested—and I think that the implication of your remarks is that aeronautics is terribly underemphasized. And one way in which you might assist the refocusing of NASA is to recreate the equivalent of the old NASA Advisory Committee on Aeronautics, NACA—

Mr. KNIGHT. I firmly agree.

Dr. SCHMITT. —and let it stand on its own, and I think it can stand on its own. From Apollo on, NACA programs contributed a tremendous amount to Apollo, but then the aeronautics research in general began to decline under those pressures. And I'd like to see a whole new emphasis in aeronautics, and I think you can do it with recreating an agency that has a focus. I like focused agencies. I really do.

Lt. Gen. STAFFORD. Congressman Knight, the one thing, too, that you need to do is coordinate with the Air Force research lab. I think this is a great way for cooperation. And there's no doubt. You brought it right out that—I've been briefed on some things the Chinese have done, and they've really advanced in hypersonics and weapons, not nuclear but just with chemicals or you put just energy, v squared over 2g, it's got a real tremendous effect. But you're right on on that. We need to get back into hypersonics.

Mr. KNIGHT. Thank you, sir.

Thank you, Mr. Chairman. I yield back.

Chairman SMITH. Thank you, Mr. Knight.

And the gentleman from Texas, Mr. Babin, is recognized.

Mr. BABIN. Yes, sir, Mr. Chairman. Thank you very much.

It's just been a real treat to hear you experts give great testimonies, and a lot of great questions have been asked and had some very enlightening answers. I have several questions that I wanted to ask but I think we've already touched on them. But there are several questions that I feel like I'd like to ask about an announcement that was made yesterday. Acting Administrator Robert Lightfoot of NASA announced that he was directing Bill Gerstenmaier to conduct a feasibility study to determine whether the first exploration mission EM-1 using SLS and Orion could be flown with a crew. It's currently planned as an uncrewed test flight, as you know. We welcome that news of this study, but some of the questions that this may elicit I would like to hear some of your opinions.

The first one, is it possible to technically justify it? Can the additional risks be justified and addressed? Should there be an off-ramp if the schedule slips too far or cost comes in too high? Is there an alternative scenario that accelerates flying astronauts—that accelerates exploration by moving EM-2 forward as well? So I would like to ask each of you. We'll start with you, Dr. Schmitt. Is it possible to technically justify this?

Dr. SCHMITT. I have no idea. I think both outside and inside of NASA are going to have to look at it very closely, whether you can man-rate the system that fast and——

Mr. BABIN. Yes.

Dr. SCHMITT. —meet the kind of kind of criteria that Tom has put forward on many occasions that meet the safety requirement. You know, the one thing that will always hurt a space program is an accident, and there's always risk and you have to be willing to take those risks, but still, you also have to make sure that you fully understand the risks that you're taking. And that I think we'll just have to wait and see. It also depends on what the Administration decides it wants to do. The next NASA Administrator will certainly be responsible for doing whatever that turns out to be.

Mr. BABIN. All right. Okay. Thank you.

Yes, Lieutenant General Stafford.

Lt. Gen. STAFFORD. Right, Mr. Babin, the space shuttle, we flew that crew on the first flight and it flew. And I was involved with that decision because at that time—it was a few years when I was head of the astronaut group with Dick Slayton. We did not have faith in the autopilots. And I think what we'll have on the SLS—we're using parts that's been there before, and the main core has four space shuttle main engines and they've been liquid engines and they've proved out over a period of time. The solid rocket boosters are elements of the space shuttle. They're a five segment now instead of four. The upper stage, they're going to have four RL10s, and those have been around for 50 years, improving all the time. And the last I saw, sir, there's been 480 straight flights. So the power plants——

Mr. BABIN. Good.

Lt. Gen. STAFFORD. —are in pretty good shape I think, so it's main thing is building the core. And I would feel better about flying this than we did other things.

Mr. BABIN. Thank you for that.

Dr. Stofan?

Dr. STOFAN. You know, obviously the approach Robert's taken by having Bill Gerstenmaier do a study I think is the correct one and NASA will, whether it's commercial crew or whether it's the SLS Orion flight, will always put safety first. Would I personally love to see the schedule accelerated? Yes, I would love that. The sooner we get to Mars, the better.

I think a bigger issue is one that we touched on earlier is that flight rate of SLS and Orion going forward after that first flight, which I think is still an ongoing concern.

Mr. BABIN. Yes. Okay. Mr. Young?

Mr. YOUNG. Yes, just to add my comments. I think doing the study is good so I applaud that. A little bit of what Ellen just said, you know, I would actually add a part B to it, and that is, God, it's a long time between the first flight and the second flight today, you know, the plan with the first one being un-crewed and the second one some few years later, which I don't remember the exact number of years but some years later with a crewed. And so part B in my mind if you're really going to take a hard look at this overall plan is how can you accelerate it so that you do the first one and then within a few months after it you do the second one?

You know, somebody commented earlier about the number of flights of the Saturn V within a year——

Mr. BABIN. Right.

Mr. YOUNG. So I think whether the first one ends up being crewed or un-crewed as the current plan is, the second one being as soon after it as is practical, meaning a few months, which is probably a budget issue but would be a responsible thing to consider.

Mr. BABIN. Thank you very much. And, Mr. Chairman, I yield back.

Dr. SCHMITT. Just——

Mr. BABIN. Does somebody have something else? Yes, sir.

Dr. SCHMITT. Just quickly, a little history, the first full-up use of the Saturn V with a crew was the Apollo 8 mission around the Moon, so you're saying can we do that now with the SLS, the same kind of thing.

Mr. BABIN. Same answer that——

Dr. SCHMITT. And the Apollo 8 mission of course was sort of an afterthought when we were running behind schedule on the lunar module, and they actually had had problems with the Saturn V on one of the un-crewed launches, and that had to be—the pogo problem in that case. And they even had some of that problem on the Apollo 8 launch.

So you have to make sure that you really understand your launch systems and the full-up system is what's important. And that was Dale Myer's orders to von Braun is let's launch this thing full up finally because von Braun would have tested it to death. I think even he admitted that later.

Chairman SMITH. Okay. Thank you, Mr. Babin.

Mr. BABIN. Thank you, Mr. Chairman. Thank you.

Chairman SMITH. The gentleman from Louisiana, Mr. Higgins, is recognized.

Mr. HIGGINS. Dr. Schmitt, in your long list of accomplishments, your bio, you've helped to uncover much of the geological history of the Moon and its relationship to the early history of the Earth, further definition of the violent impact history of the Earth during the period when life began, the potential role of the largest impact basin and the evolution of the Moon, identification of samples of the lunar mantle, the definition of the sequence of formation of three large lunar basins, the list goes on and on but it does not mention that you were certainly the only pilot in history that almost landed a lunar modular on an aircraft carrier.

Dr. SCHMITT. Well, you know, thank goodness the Navy moved the carrier because our guidance system was so good we were about to hit the carrier.

Mr. HIGGINS. You were on target. I bring that up, that aircraft carrier was the USS Ticonderoga. My father was a Navy pilot in World War II and had the honor of serving on that aircraft carrier. My father was a fiercely patriotic man and did not trust the Chinese or the Russians. Perhaps by the nature of my DNA but certainly through the course of my life and in view of recent events politically and space-based, neither do I.

So my question to you, sir, is regarding America's interest in maintaining a persistent human presence in space, be that human

presence on the frontier, in a low-Earth orbit, geostationary, or an American human presence based on the Moon, is it necessary that we involve international partners as we push the frontiers of the American space program?

Dr. SCHMITT. I personally do not think it's necessary. I think it takes the United States to be the leader of a program, as it was in Apollo. We had international partners to some degree in Apollo. We certainly had a lot of international participation by some of the engineers, and the lunar sample analysis program was an international program. So yes, but it takes our leadership. I think we need to be in charge in order to provide an opportunity for international partnerships.

But no partnership, I think, should be in the critical path. If you're going to go to Mars by way of the Moon, that critical path has to be our responsibility. You can't be waiting for some other partner to deliver and to make—and—again, I think it's just absolutely essential that there be a leader of these kind of programs.

Mr. HIGGINS. I concur and thank you.

Lieutenant General?

Lt. Gen. STAFFORD. Yes, sir. I like what Dr. Schmitt said. We—America needs to be a leader. If you're going to be first in the world, you need to be first in space and we have to be a leader. And I've been deeply involved with the International Space Station, the partners. I've been deeply involved earlier with the Soviets and now the Russians. And to me you have to completely differentiate the Soviets from the Chinese. It's a whole different world.

And I've been to Russia maybe 35 times. In fact, I adopted two Russian orphan boys. So I think I understand a lot of the Russians and what it is that—it takes too long to go into it in this Committee, but the Chinese are a complete different type of effort. And so I agree with your father on the Chinese completely. And in the Russians, it's really one more of nationalistic and it's now materialistic, too. But it's a different world, and it takes too long to go into it here.

Mr. HIGGINS. That's a unique and valuable perspective. I would encourage my colleagues and the members of this committee to maintain a sharp focus on our national security as we move forward with our plans to advance the causes of NASA. And I certainly agree with this panel that has appeared before us that we need to be completely focused with the mission parameters, as laid out over the next 15 or 17 years. It seems to be the window. And I look forward to working with my committee members and colleagues on both sides of the aisle to make it happen.

Mr. Chairman, I yield back.

Chairman SMITH. Thank you, Mr. Higgins.

And the gentleman from Florida, Mr. Posey, is recognized for his questions.

Mr. POSEY. Thank you, Mr. Chairman. Thank you for calling this hearing, Mr. Chairman, and I thank the witnesses for coming here.

It's been probably five decades that I have respected and admired you and your accomplishments. The words that come out of your mouth are like gospel to me, and I just can't thank you enough for your attendance here. I was in high school when Kennedy gave his famous speech about why go to the Moon, and that became my first

priority in life was to have my fingerprints on that rocket that took our men to the Moon and return them safely. And in general I appreciate you pointing out the third stage references a while ago, and that was my stage. And I'll forever be proud of that. A little bit of a lump.

You know, poll after poll, study after study, survey after survey shows the general public thinks we spend 20 to 25 percent of our budget on space. And we all know it's more like 1/2 of one percent. And they don't understand the benefits. They don't understand the importance to our national security, the ultimate military high ground, the economic, the STEM as you so well pointed out, the benefits of it. And so, you know, we're trying to change that.

And we're trying to make sure or ensure that NASA considers everything that they do as a steppingstone to going to Mars. We think that's got to be the priority. When everything is a priority, nothing is a priority. And that's where we are now so, you know, kind of playing whack-a-mole.

I usually carry around a chart that has like over two dozen missions to nowhere started by one Congress or one Administration and canceled by another. And you mentioned, Lieutenant General, a little while ago we'd probably be on Mars now if we had stayed the course last time. That's really a big problem that we have.

Selling our colleagues on the importance of space is not an easy job either. The people on this Committee all respect space and are enthusiastic about space, and you ask anybody on my staff what do you do in Congress, well, the first thing we do is we still sell space every day in every way. You know, it's important. And you all remember when the space station survived by just one vote in Congress.

So we keep a running list, a hit list, who's with us, who's against us, who says they're with us, who's not. And we try and keep this in perspective, but, you know, we've seen a budget—NASA budget take hits for a big city cops police plan. We've seen another department take money out of NASA to do a responsibility they're already tasked with and they're already funded for. You know, the NASA budget is kind of like—been like a big piñata occasionally, and we want to see that doesn't continue.

But we have to sometimes consider that maybe NASA is not our biggest assistant in this. And I want to share with you one time, you know the beautiful educational and impressive press kits that we did for each shuttle launch that anybody came to one of those, there's a decal and the stories and the stickers and the pins and, I mean, very impressive. If you went to launches, you'd see people clutching these valuable things.

And so when they did the last shuttle launch, I contacted my local NASA P.R. people and said, look, I'd like to get 434 press kits, and I'd like to make it a priority next year to deliver one to every Member of Congress and talk about how this would be a treasure for their grandchildren and, you know, there won't be any more of these and give me the opportunity to discuss one-on-one and have something in hand because Members' times are valuable.

Well, my local P.R. people used to work to get that for me but NASA Washington said no. They said that's not your job. So you know who did it? Nobody did it. And it's a great opportunity lost.

So, with the time remaining I'd kind of like your thoughts on promotion, where you think we could do more, where we could be more persuasive with NASA.

Lt. Gen. STAFFORD. Well, you're my Congressman now since I live in Satellite Beach.

Mr. POSEY. Well, you and Buzz both.

Lt. Gen. STAFFORD. Yes.

Mr. POSEY. Well, thank you. Don't hesitate to call on me, Lieutenant General.

Lt. Gen. STAFFORD. Right. But, you know, what I've observed over the years—and, Jack, I'd like your opinion, too—one of the weaknesses of NASA has been its public relations.

Mr. POSEY. Yes.

Lt. Gen. STAFFORD. That goes all the way back starting with Gemini. And I remember George Low was so aware of this when he was the Deputy Administrator. But it's been there and is something that you brought out very well.

Mr. POSEY. Thank you. Thank you.

Dr. SCHMITT. When I was chairing the NASA Advisory Council, it was—this was something that came up and the budgets that were being allocated for outreach and education—and I'm not sure where that allocation came from, whether it was within NASA the OMB or the Congress, but for this kind of outreach that you described budgets were going down and they probably are even lower now than they were then. And we raised that issue and it was one that apparently was unresolvable. And my memory is not clear exactly if I ever was clear on why it was unresolvable.

When Tom and I were active, NASA did have a reasonably good outreach program. If you weren't assigned a crew, for example, there was your week in the BARREL, and about every 8 months we would be given to NASA headquarters to fill requests from Congress and elsewhere for appearances. And so for a week about five or eight times a day we would fulfill these requests all over the country. That was excellent. They also had a van—several vans that would go around the country and visit schools and other facilities. I was told hundreds of times how effective those vans were in outreach to school systems.

Mr. POSEY. Yes.

Dr. SCHMITT. So there—it's not that NASA hasn't had a history of knowing how to do that. It's just that right now my understanding the budgets don't exist, and I know the vans don't exist anymore. And I don't think that the week in the BARREL exists anymore because my understanding is if you want an astronaut appearance, the sponsor has to pay all the transportation, everything, all the costs. So if you want a better outreach program, the funds have to be there to do it.

Mr. POSEY. Thank you. Thank you, again. Anybody else?

Dr. STOFAN. If I could just point out, NASA partners with museums all around the country. We touch thousands of kids every day through Boys and Girls Clubs programs. We reach kids in after-school programs. Our social media sites are some of the most popular in this country.

But I would also point out that the way we get the most people engaged in NASA is Curiosity landing on the surface of Mars, the

Pluto encounter. Every time you're going to see SLS launch, when we see commercial crew on its way to the space station, these are the ways we engage the public, by doing great and amazing things. That's our best outreach.

Mr. POSEY. Well, and I think that's awesome, and I liked on their website where you can buy a ticket to the Moon now—I mean, a ticket to Mars. I went on and applied. I'm still waiting 14 months but, you know.

Chairman SMITH. The gentleman's time has expired.

Mr. POSEY. Thank you, Mr. Chairman.

Chairman SMITH. Thank you, Mr. Posey.

The other gentleman from Florida, Mr. Webster, is recognized for his questions.

Mr. WEBSTER. Thank you, Mr. Chair. Thank you for putting together this fantastic panel, the best one I've ever had in my whole time in Congress is this group. I've learned a lot.

I would like to ask Dr. Schmitt a question. In your presentation, you gave quite a few items on the key to success of the Apollo program, and one of those was the sufficient base of technology. And my question is is that base knowledge or is it hardware or is it people? What were you speaking of when you were saying that you need a sufficient base of technology?

Dr. SCHMITT. Well, thank you, Congressman. It's an important question. Before Apollo we had the component base of technology, the engineering understanding of many aircraft systems and some spacecraft systems that came out of the World War II and the Cold War, primarily out of the Defense Department. There was that kind of understanding.

The X-15 program was an extraordinarily important part of the NACA, the National Advisory Committee on Aeronautics, activities that fed into NASA both in terms of understanding flight in difficult regimes but also because Bob Gilruth, who was the head of the Space Task Group, had managed—and they were managing the X-15 program. So that knowledge, that managerial knowledge was a very important component.

But we also inherited the managerial knowledge from a Canadian aircraft program that was canceled by Canada, the Avro Arrow aircraft program. And many of the people that came into NASA particularly in flight control—John Hodge and the like—were out of that Canadian Arrow program. Gilruth had made a specific trip to go up there and recruit.

So that's what I'm talking about when I say a base of technology. It's not only the components, the microelectronics that were just coming on, some of the materials that were just coming on, but it's also, if you will, the technological understanding of how to manage complex programs.

And now, today, I think we're in much better shape, as I said in my testimony, than we were for Apollo. The base has much expanded, primarily because of the innovations in the private sector, the advance of computer technology. We were advancing it for Apollo, but all of a sudden it took its own legs and ran within the private sector. So that base right now from the point of view of both flying and manufacturing is so much stronger today than it was for Apollo.

So I really think that if you all and others decide let's go, let's focus, we're ready to move. I think we can make progress and we can get up to a heavy-lift launch a year. In fact, that was probably the biggest mistake we made, and it started way back in the Johnson Administration is that we only bought 15 Saturn V's. And the Nixon Administration confirmed that decision. We should have had that production line going continuously and launching a couple times a year, and we would have met that 2016 date without question. The Saturn V was a very robust system and could have done everything that we've done since and more.

You got me started on something that—

Mr. WEBSTER. Well, let me ask another question about the funding. I was thinking as we were talking about prioritizing, which I think is a great thing, and we pick our spots and maybe all of them are laudable but we can only do so many and if we focus all of our money there, then we'll accomplish the goal. Is there any thought that the other ancillary savings that come from the advances made by space exploration could be funded from areas that we're spending—maybe futilely spending money on trying—for instance, someone said that every time there's a launch, there's a heightened interest in STEM education.

Well, if that be the case, maybe we spent too much on getting consortiums together and funding those and trying to figure out how we're going to encourage somebody who's in the seventh or eighth grade to begin thinking about becoming an engineer or something else in the technology sense. Maybe there's a broader prioritization that could take place. Maybe there's advances made in health care or maybe there's advances made in other things and technology that come from space exploration that we're funding but maybe we're funding and the results are way less than would happen if we were just doing that. Do you have any comments about that?

Dr. STOFAN. You know, the problems with funding basic research, whether it's in technology development or in scientific areas is you really don't know where those spinoffs are coming from. Every day—every year at NASA we publish a spinoff book about this thick of spinoffs that have come off. If we could predict every one of those, I would agree with you, but the problem is we can't. And so when you're investing in basic research, basic science, basic technology, you don't know where the payoff is going to be. You just know there's going to be payoff because we've demonstrated that in this country for well over 50 years.

Mr. WEBSTER. Anyone else? Yes.

Lt. Gen. STAFFORD. Well, one thing, again, all of us have talked about and the Chairman has talked about is the stability, is—that does not change between when Administrations change. And the first time this ever happened was when the Clinton Administration came in because, you know, it was President Reagan that started the space station and that continued on. President Nixon started the space shuttle and that continued on whether it was Democrat or Republican. And then it started with the Clinton Administration and the next time it happened, bang, was with the last Administration. And those two square waves really set us back.

Mr. WEBSTER. Okay. Thank you very much. I yield back.

Chairman SMITH. Thank you, Mr. Webster. And let me thank all of our experts for being here today. You could clearly tell by the participation and by the enthusiasm of our members that we all support America's initiatives in space, and you all have been a big part of that for many, many years and I hope will continue to be a big part of that as well. So thanks again.

Feel free to contact us any time with your advice and counsel. We would look forward to that.

And we stand adjourned.

[Whereupon, at 12:41 p.m., the Committee was adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

*Responses by Hon. Harrison Schmitt***HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
QUESTIONS FOR THE RECORD**

“NASA: Past, Present, and Future”

Honorable Harrison H. Schmitt, PhD, Apollo 17 Astronaut, Former United States Senator

Questions submitted by Chairman Lamar Smith, House Committee on Science, Space, and Technology

1. NASA, in cooperation with Congress, has been able to enhance programmatic continuity by shifting development to focus strongly on capabilities (rather than destinations), particularly in the continued support for the Space Launch System and Orion. Would you recommend further Congressional support for the development of additional systems that would expand or enhance core capabilities? If so, are there particular systems or space-based infrastructure that Congress and NASA may want to prioritize in coming years?

Answer: Mr. Chairman, in spite of the Constellation Program being cancelled by the previous President, the Congress and a few leaders in NASA have been able initiate the development of capabilities that allow the United States to choose the Moon and Mars as destinations for a new generation of Americans. I would recommend that choice be made as soon as possible with specific milestones to be accomplished. This choice is as much a geopolitical one as it is for any of many other worthwhile aims. Having said that, I would recommend Congressional support for the development of lunar and planetary landing capabilities and long duration roving systems, building on the work done in Constellation, and for the development of a multinational (not under the UN) claims regime for the Moon that would encourage investors to join with the government in returning to that destination in support of ultimately sending Americans to Mars. (I outline what such a claims regime might look like in Chapter 12 of my book, *Return to the Moon*, Springer, 2006.)

2. In your opinion, is there room for more cooperation between NASA and other government agencies, such as the Department of Energy? What are some areas you would prioritize for further cooperation?

Answer: As was discussed at the hearing, NASA needs to focus on the future of Americans in deep space – its current activities and expertise that support the work of other agencies should be considered for transfer to those agencies as well as spinning off the strategically critical work in aeronautics into a separate, well funded NACA-like agency. As one of the future economic values of lunar resources is fuel for environmentally benign helium-3 fusion power (nuclear power without nuclear waste), cooperation between NASA and DOE to encourage private sector development of related fusion technology would do a lot to bring

private investment into a return to the Moon effort. This cooperative R&D effort in fusion power also is justified on national security grounds as well as feeding into the need for an interplanetary booster to go to Mars.

Unfortunately, my impression for some 20 years or more has been NASA has never believed that DOE was serious about developing fusion power alternatives to deuterium-tritium fusion and DOE never believed that NASA was serious about going back to the Moon. Someone needs to bring them together along with private investors.

3. In the hearing, other witnesses suggested discussing potential lunar efforts as development, enabling, and staging efforts for subsequent missions to Mars and elsewhere in the solar system. Do you think such a framing helps mitigate the persistent difficulties NASA encounters from frequent changes in direction and demands that it keep too many options open?

Answer: I do agree that such a framing would help, particularly, if accompanied by specific milestones, adequate management reserves of funding, and the creation of the management system I recommended in my prepared testimony.

4. Based on your experience as a geologist, as an astronaut, and your work on He3, are there other opportunities to make a presence on the Moon a commercially or economically viable?

Answer: Once an viable settlement exists on the Moon, with long-term economic stability based on supplying Earth with helium-3 fusion fuel, then the by-products of helium-3 production and settlement operations (H₂O, O, H, He, N, C, and food) will have economic value to other space activities. Also, the existence of a settlement can be marketed internationally to support lunar research stations and exploration. With the attainment of the low launch costs required for the economic viability of helium-3 production (less than \$3000/kg¹), even lunar tourism may become economically viable for some. Of course, once a decision is made to return to the Moon, private capital and management might contribute resources to the creation and implementation of resource production.

¹ Schmitt, H. H., 2006, Return to the Moon, Springer.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

“NASA: Past, Present, and Future”

Honorable Harrison H. Schmitt, PhD, Apollo 17 Astronaut, Former United States Senator

Questions submitted by Ranking Member Eddie Bernice Johnson, House Committee on Science, Space, and Technology

1. In your written statement, you suggest that the next major goal for NASA’s human exploration program should be returning humans to the surface of the Moon in preparation for the eventual human exploration of Mars. What, in your view, does NASA need to learn from lunar surface activities in preparation for a human mission to Mars that it can’t learn in cis-lunar space?

Answer: Congresswoman Johnson, I would suggest that renewed deep space exploration and a path to Mars that includes a permanent settlement on the Moon is more than the next major goal for NASA but is one of the next major goals for America. The Moon’s role in achieving that goal and providing future generations with a permanent role in deep space is multifaceted. Its resources will be invaluable to both deep space activities and the Earth. Operational experience will prepare future generations of skilled workers, engineers, scientists and managers for the challenges and risks of and indefinite future of deep space flight. Simulations of Mars landings and surface activities on the Moon will feed into future plans for Mars in the face of both the challenges of the thin Martian atmosphere, partial gravity, sampling challenges, and the lack of real-time communications with the Earth. A permanent, self-sustaining lunar settlement also would begin humankind’s quest to no longer be a single planet species.

- a. How would you ensure that the Moon does not become a costly and time-consuming detour rather than a stepping stone toward sending humans to Mars?

Answer: The Congress should require that a return to the Moon be fully integrated in its engineering, scientific, operations and objectives with the long-term goal of Americans reaching and exploring the surface of Mars.

- b. Are you proposing that NASA abandon efforts to develop the capabilities needed to send humans to Mars and redirect them towards human exploration of the Moon? Or are you suggesting that NASA’s budget be increased to support both human exploration of the Moon and Mars?

Answer: Human activities on both the Moon and Mars should be the focus of NASA, including robotic lunar and planetary exploration and physiological research on the International Space Station. If NASA is relieved of its many other unrelated responsibilities, its budget may not need to be increased; however, the annual funding and management reserves required to reach reasonable lunar and Martian program milestones would need to be studied very carefully. If a major

deep space program is authorized and appropriated for NASA, then Congress should consider multi-year funding with, of course, close oversight on the progress and efficiency of the program. Once a decision is made to return to the Moon, private capital might contribute resources to the creation of lunar resource production capabilities.

- c. If NASA's budget could not be increased to such levels, are you suggesting that resources be provided by moving funding from other NASA programs?

Answer: Depending on well-considered costing of the deep space effort, including appropriate management reserves, those unrelated budget resources could be used; however, I also would transfer those programs and expertise, whose national importance warranted it, to other agencies with similar or the same responsibilities, e.g., astronomy to the National Science Foundation (NSF), Earth-sensing to NOAA and the Department of the Interior, and aeronautics to a re-created National Advisory Committee on Aeronautics (NACA). As suggested in my prepared testimony, the Congress also might consider the creation of a National Space Exploration Administration to focus only on the management of deep space exploration with NASA continuing to manage its other activities including our international responsibilities relative to the International Space Station.

2. In your written and oral testimonies, you spoke of the need to maintain an average age workforce of less than 30 years. Do you see a place at NASA for those who have gained the knowledge of human spaceflight over years, if not decades, including both the successes and the tragedies?

Answer: There is no question that middle and senior management personnel would provide the relevant knowledge of the past as they would be drawn from those previously younger personnel who have demonstrated the judgment and breadth of experience required to be managers. The agency's core of skilled workers, engineers and scientists, however, should always remain young.

3. NASA scientists recently narrowed down their list of potential landing sites for the Mars 2020 rover to three candidates. As you know, that mission will extract and cache samples of Martian rock and soil for a future mission to collect and return to Earth where they can be further studied.

- a. As a field geologist, can you explain the benefits of having humans on Mars to identify and collect science samples?

Answer: Humans who are broadly experienced and knowledgeable in their professional fields, no matter what those fields may be, bring that experience and knowledge to bear up on exposure to new domains relevant to their fields. Test pilots are critical to evaluating new aircraft. Surgeons are critical to evaluating new surgical challenges. And so forth. In a similar vein, experienced field geologists evaluate new observations of nature's lunar and planetary handiwork.

The instantaneous reprogramming of the experienced human brain when faced with new information is the critical ingredient in all such situations.

There is no question that a robotically collected cache of Martian samples would be scientifically valuable; however, even more valuable would be a cache of samples collected and documented verbally and photographically by an experienced individual within the three dimensional context of the sample locale being investigated.

- b. What challenges do humans bring to the search for extant or past life on Mars?

Answer: There is a significant possibility the life began and evolved to a limited extent in the clay, water and organic-rich environment that existed on Mars early in its history, as obviously was the case on Earth. There is little possibility, however, that extant, carbon-based life still is present in the extraordinarily hostile surface environment of Mars today. This surface environment on Mars is nearly as hostile to life as is the Moon's.

On the other hand, simple life forms may have maintained themselves at a geologically stable horizon at depth, where water below and ice above are in stable contact. The depth of that horizon varies with latitude. Until a core through that horizon is studied, it will not be known if life is present. Obtaining that core without exposing humans to possible risks or contaminating the core will require sophisticated equipment and operations. It may well turn out, as we have learned from lunar experiences, that humans, with the facility of instantaneous judgment, can obtain such a core better rather than robots, although *in situ* use of tele-robotics may be involved in either circumstance. I am not aware that a definitive study of these coring and analysis activities has been carried out, as it certainly should be prior to an attempt to core to the water-ice horizon.

The search for fossils of extinct life forms will follow traditional field geological practices, including high-resolution visual and chemical studies of samples.

- c. What if anything needs to be done now to ensure that NASA's Mars planning takes scientific goals such as sample collection into account?

Answer: The definitive study of how to core to the water and ice horizon, discussed above, and to definitively analyze for extant life, needs to be done. It might be wise to have this done by two or three independent engineering and scientific teams.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

“NASA: Past, Present, and Future”

Honorable Harrison H. Schmitt, PhD, Apollo 17 Astronaut, Former United States Senator

Question submitted by Representative Jim Bridenstine, House Committee on Science, Space, and Technology

1. With the currently planned low launch cadence we should maximize the utility of each SLS launch. Do you think NASA should also look at sending some sort of robotic lander, particularly one of the several that are being developed by commercial entities, on EM-1?

Answer: Congressman Bridenstine, that is an interesting thought. It might be worth NASA issuing a Request for Information (RFI) to the private entities currently working on robotic concepts. This RFI probably should include some broad engineering constraints relevant to Orion and SLS.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

“NASA: Past, Present, and Future”

Honorable Harrison H. Schmitt, PhD, Apollo 17 Astronaut, Former United States Senator

Question submitted by Representative Charlie Crist, House Committee on Science, Space, and Technology

1. As a Floridian and former Governor, I understand just how integral the space industry is to the state’s culture and economy. As you know, Florida was hit extremely hard by the end of the Shuttle program. We’re recovering, but more can surely be done. You mentioned the importance of having a young workforce to help energize deep space exploration. What are your suggestions for attracting a younger workforce to the space industry — and to Florida in particular?

Answer: In this regard, Congressman Crist, it is absolutely essential that basic K-12 education emphasize mathematics and critical thinking along with reading, writing, history and basic science. At the same time, vocational training in the skills required for modern manufacturing should be expanded. Far too much K-12 “education” is not relevant to the future needs of the nation, much less the student. The “Sputnik Generation” that accomplished the Apollo Program did not just appear – they were products of a far better K-12 public education system relative to those times than exists today in far more complex times.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

“NASA: Past, Present, and Future”

Honorable Harrison H. Schmitt, PhD, Apollo 17 Astronaut, Former United States Senator

Questions submitted by Representative Jim Banks, House Committee on Science, Space, and Technology

1. From my perspective as a veteran and member of the Armed Services Committee — secure, assured access to space should be a priority as we confront growing challenges around the globe. So, while we often hear that civil space activities are important to our national security, how exactly do you think NASA makes our country safer?

Answer: Congressman Banks, I believe that a competitive national position in the non-military exploration and utilization of space directly influences the perceptions of Americans and international observers about the overall strength and vitality of the United States. This was demonstrated by President Eisenhower’s and Congress’ geopolitical rationale for NASA’s formation in 1958 and Eisenhower’s quiet and Kennedy’s public support for the Apollo Program in the early 1960’s. One can imagine the adverse consequences in the Cold War if the then Soviet Union had landed men on the Moon first or if the United States had failed. Indeed, it can be legitimately argued that the fact that NASA succeeded in landing on the Moon, and they did not, played a major role in the psychological demise of the Soviet Union when faced with the challenge of President Reagan’s Strategic Defense Initiative. Apollo appeared to indicate to Soviet Leadership that we could succeed with SDI and they could not.

In that vein of history, consider a future situation, closer to reality than many would like to believe, where China dominates deep space in what has become a *de facto* Cold War II.

This geopolitical argument is in addition to the stimulus that “civil space activities” have in advancing education, technology, economic health, and American confidence in the future, all of which relate directly to national security. In this context, it is often overlooked that commercial communication satellites are a national defense resource as are weather and Earth-sensing satellites. Commercial comsats have been driving technology development in this arena for decades, particularly with respect to the dispersion of fleets of such assets, as one means of mitigating asymmetric warfare against our national communications assets.

2. What can we do in Congress to capitalize on the important partnerships being fostered between NASA and the private sector?

Answer: As is the case for all economic activities, Congress can continue to encourage private investors through creating a more rational tax and regulatory environment than currently exists for innovation and entrepreneurial risk-taking. In addition, Congress should consider the following more specific actions:

- Require NASA to issue a Request for Information (RFI) on how truly commercial (not subsidized) private investment initiatives could be integrated into a permanent lunar base or settlement plan.
- Require NASA to issue a Request for Information (RFI) on how truly commercial private investment initiatives could utilize the capabilities of the Space Launch System in order to increase launch rates and reduce costs.
- Require the Departments of Commerce and State to propose to Congress the detailed outline of a Lunar Claims Regime¹ that the United States would recognize internationally as the basis for the production of lunar resources. Precedent for this exists in the “Deep Seabed Hard Minerals Act” of 1984 and a subsequent multilateral agreement between the United States and several other nations relative to licensing of seabed mining.
- Unequivocally, express the opposition of Congress to the UN sponsored “Moon Agreement” of 1979 the provisions of which would internationalize the management of lunar space resource development and effectively block private initiatives licensed by the United States. This opposition probably would be best expressed through a Joint Resolution signed by the President. Fortunately, the Senate has never ratified the Moon Agreement.

¹ Schmitt, H. H., 2006, Return to the Moon, Springer, p. 293-294.

3. NASA has played a critical role in procuring weather satellites for NOAA to operate. A company (Harris Corp) in my district in Fort Wayne, IN has been making satellite instruments for NASA for 50 years – including many of the instruments used by the U.S. in space today. What should NASA’s role be in weather satellites and what is best way to ensure the US doesn’t have a gap in weather satellite coverage?

Answer: If NASA were to be re-chartered and enabled to focus on the implementation of a Deep Space Exploration Program, as I have suggested in my prepared testimony, then responsibilities for important but unrelated activities should be transferred to other agencies with comparable responsibilities. In the case of weather and climate-related satellites, NOAA should be able to manage their procurement, particularly if the expertise currently in NASA for procuring such satellites from industry is transferred along with the responsibility. The same can be said of NASA’s current responsibilities and expertise in Earth-sensing satellites that could be assumed by the Department of the Interior and astronomy that could be assumed by the National Science Foundation.

Responses by Lt. Gen. Thomas P. Stafford

**HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
QUESTIONS FOR THE RECORD**

“NASA: Past, Present, and Future”

Lieutenant General Thomas P. Stafford, Gemini VI, Gemini IX, Apollo 10, Apollo-Soyuz Test
Project Astronaut; Chairman, NASA International Space Station Advisory Committee

Questions submitted by Chairman Lamar Smith, House Committee on Science, Space, and
Technology

1. In your testimony, you discussed the National Space Council and its potential value in the support and execution of future human spaceflight initiatives. Could you briefly expand on this and outline what authorities the National Space Council should have, and how it should interact with other executive branch offices to ensure that it is not simply another layer of bureaucracy?

Answer: I did support the National Space Council based on my experience during the Gemini, Apollo and Skylab programs. The Office of Management and Budget has very little oversight. During the Augustine Commission, Mr. Paul Shawcross noted that without specific directions from the president, it is his office that gives orders to NASA. With the vice president running the National Space council, as was the case in the Johnson administration, orders were given with an iron fist. The NSC sets basic policy and direction.

2. Cooperation with leading spacefaring nations such as Russia and China both come with potential gains and risks. What are your thoughts on the best way for the US to engage with those and other spacefaring nations to support future US-led human space exploration?

Answer: The best way to engage is for America to take the leadership. I believe a heavy lift vehicle is the key to this. We are the only country that will have this capability in the future.

3. The May 1991 report *America at the Threshold: America's Space Exploration Initiative* addressed human spaceflight issues, concerns, and architectures at great length. What fundamental, underlying conclusions and recommendations from that report are the most relevant and significant to current debates about the future of NASA's human space exploration efforts beyond low-Earth orbit?

Answer: The first thing you need is a heavy lift launch vehicle. Development of that vehicle is underway. I was deeply involved with its development during the creation of the 2010 NASA Authorization Act. The heavy lift vehicle starts at 70 metric tons, at a minimum, and goes to 130 tons, and it could go to 160. When I flew to the moon, the Saturn V had 138 metric tons. The lift capability determines what you can send to space, and that relates to Tsiolkovsky's equations. You cannot get around Tsiolkovsky and Newton. In *America at the*

Threshold, we say heavy lift with a minimum capable of 150 metric tons is desired, with the ability to go up to 250 metric tons. In terms of nuclear thermal propulsion, it is not necessary to go to the moon. To go to Mars, it greatly reduces the time. It would also be important to have a nuclear power source on Mars. To make any meaningful use of it, it would need probably a minimum of four or five megawatts, maximum up to 10. The problem there is heat rejection. The reactor would require a gigantic radiator.

Above all, America should invest in mission architectures. Critical technologies include; Autonomous rendezvous and docking, cryogenic fuel transfer and long-term storage and radiation hazard mitigation. I refer to solar radiation, not galactic cosmic rays. Water can serve as a good radiation shield, and we must understand how to recycle water resources in space. The last technology we should invest in is in situ resource utilization, such as processing water, hydrogen and oxygen from outer space materials.

4. You are well acquainted with the risks associated with human spaceflight. The hostile outer space environment poses even more danger as we leave Earth's immediate neighborhood. As the nation looks forward to potential missions to the Moon and Mars, do you see any room or need for change in NASA's approach to spaceflight safety?

Answer: We have all identified the need to greatly reduce solar radiation, even in the space station. Radiation is a problem even down below the Van Allen belt. For an example by just walking around on Earth, we receive about six millisieverts or radiation a year. At an altitude of 250 miles, below the Van Allen belt, astronauts experience about 6/10 of a millisievert a day, so in 10 days they experience what we get in one year. Remember that water can serve as a radiation shield. Other shielding concepts include inflatable habitats. Remember, many of our questions about radiation exposure have been answered aboard the international space station.

5. Is there a near-to-medium term market for heavy lift beyond NASA? Is it possible to design effective exploration architectures that make use of both the SLS as well as the commercial heavy-lift vehicles currently under development? What are the advantages, disadvantages, and risks of using a hybrid of government and privately-run systems for human space exploration and sustainment?

Answer: I do not know if there is such a market. The Department of Defense might be able to use such a vehicle for one or two experiments. Our nation cannot afford both the SLS and a commercial heavy-lift vehicle.

We must ask ourselves: What advantages, disadvantages of using a hybrid of government and privately run systems for human spaceflight? During the Constellation program, we saw the need to restructure the program, but we were only about 15% over budget and we did a restructure with emphasis on low-Earth orbit and the space station first. We would have

Americans flying on American spacecraft and boosters late 2013 or '14. Using this, quote, "commercial" program, it is going to be at least, according to the latest GAO report, 2019.

I believe current "commercial" programs are more accurately called subsidies. What was done during the Apollo program to ensure safety is not being done on these commercial programs.

I also have concerns about the safety criteria for commercial programs. If companies were launching every day or every other day, with the frequency that airlines fly aircraft, it would be one thing. But commercial companies only launch a few times per year, which changes the situation.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

“NASA: Past, Present, and Future”

Lieutenant General Thomas P. Stafford, Gemini VI, Gemini IX, Apollo 10, Apollo-Soyuz Test Project Astronaut; Chairman, NASA International Space Station Advisory Committee

Questions submitted by Ranking Member Eddie Bernice Johnson, House Committee on Science, Space, and Technology

1. In your written statement, you suggest that the next major goal for NASA’s human exploration program should be returning humans to the surface of the Moon in preparation for the eventual human exploration of Mars. What, in your view, does NASA need to learn from lunar surface activities in preparation for a human mission to Mars that it can’t learn in cis-lunar space?

Answer: We asked ourselves the same question. Why do we need to go to the Moon to go to Mars? Well, Mars has 38% gravity, while the lunar environment is 16%. We would design things to go to Mars, but put them on the Moon, and there, work out the environmental control system and the recycling, the radiation protection, everything. The Moon is only three days away. If we go to Mars, we can only launch once every 26 months, and there’s certain times it’s just nearly impossible for the energy required per kilogram to get out there. It takes forever.

- a. How would you ensure that the Moon does not become a costly and time-consuming detour rather than a stepping stone toward sending humans to Mars?

Answer: Very good question. This all has to be integrated, as the Moon is a testing ground to go to Mars. Here, the National Space Council has an oversight role to help set priorities and policy. If they do not, the other option is NASA tries to put their funding towards the Moon rather than integrating it into going to Mars, and the only ones that really guide that is Congress.

- b. Are you proposing that NASA abandon efforts to develop the capabilities needed to send humans to Mars and redirect them towards human exploration of the Moon? Or are you suggesting that NASA’s budget be increased to support both human exploration of the Moon and Mars?

Answer: Regarding the first part of your question, no. Absolutely not. As for the second part of your question, it has to be a balanced budget. I don’t think we are going to get a lot more money. We should go to the Moon, just do the minimum of what it takes to certify equipment, and then go on to Mars. Doug Cooke, former associate administrator of NASA’s Exploration Systems Mission

Directorate, has spent years working on this, and could probably give you a more in depth answer.

- c. If NASA's budget could not be increased to such levels, are you suggesting that resources be provided by moving funding from other NASA programs?

Answer: I wouldn't necessarily suggest moving resources and funding from other NASA programs, but one option is to shut down the space station. It's 24 years old, and that would free up quite a bit of money. Other than that, I don't have a clear vision of taking money from one program and moving it to another. I know that NASA has taken on several additional roles, like the environment, something that should probably be over at NOAA or the EPA, so reducing those additional roles might also make more funding available.

2. In your written and oral testimonies, you spoke of the need to maintain an average age workforce of less than 30 years. Do you see a place at NASA for those who have gained the knowledge of human spaceflight over years, if not decades, including both the successes and the tragedies? The Subcommittee on Research and Technology of the Committee on Science, Space, and Technology will hold a hearing titled National Science Foundation Part II: Future Opportunities and Challenges for Science on Tuesday, March 21, 2017 at 10:00 a.m. in Room 2318 of the Rayburn House Office Building.

Answer: This is a tough one. You would like to have the workforce somewhat less than 30 years, but you know, you could go to 40. The main thing that you want is people that are productive.

3. NASA scientists recently narrowed down their list of potential landing sites for the Mars 2020 rover to three candidates. As you know, that mission will extract and cache samples of Martian rock and soil for a future mission to collect and return to Earth where they can be further studied.

- a. As a field geologist, can you explain the benefits of having humans on Mars to identify and collect science samples? What challenges do humans bring to the search for extant or past life on Mars?

Answer: Well, I'm not a field geologist, but I do have a lot of geological training. Jack Schmitt, however, is a real field geologist. The radioisotope generator rover, the Curiosity, has been on Mars for three plus, nearly four years. It finally covered, in the last three and a half years, what Gene Cernan and Jack Schmitt did in three days on the Moon. So that's the difference. Also, if you see something, boom, you can study it right there. I don't think any scientist today doubts the viability of having a trained field geologist there looking through that helmet and working right there.

- b. What if anything needs to be done now to ensure that NASA's Mars planning takes scientific goals such as sample collection into account?

Answer: They've done a lot of planning, I think they're in pretty good shape. I don't know the specifics. Jack Schmitt may know, but Doug Cooke would really know.

4. How adequate are the contingency plans set in place by NASA and its international partners to respond should ISS operations be disrupted or access to the Station compromised? How viable are the crew and cargo transportation options currently available to NASA? What more needs to be done to ensure we have continual access to the ISS through at least 2024?

Answer: Well, in the ISS oversight committee, we looked at all types of contingency operations and emergence deorbit of the station, all of that. So, I think the contingency plans are pretty good.

Regarding the viability of the crew and cargo transportations, they've had three explosions, two launch pads greatly damaged. They're behind by years. The Russians are very much on schedule. I'll put it bluntly, this "commercial" and these Space Act Agreements are really bad things. I headed Air Force research, development and acquisition, and that's when all this started in the Air Force. We did it with a regular contract. And, from the time I had the contract for the F-117A Nighthawk signed to the first plane flew was a little bit less than two years and eight months. And, I didn't have any Space Act Agreements, either. We accounted for every dollar. So, all it takes is some tough management, and capping it at just a very low level, any Space Act Agreements. It's under other transaction authority. I think that's FAR 12. That was never, ever meant to be a multi-billion dollar, multi-year procurement.

To address the ISS through 2024, I hope the Russians keep flying. Because right now, they've come through and we're stuck with them, I think realistically, until 2019. Even though Elon Musk is the main one that keeps promising, Boeing, too, they don't say too much. They don't slip a schedule in. They're not too verbal. The whole commercial thing has been, to me, just a semi-disaster. If you want to count the cost per pound, or kilogram if you work that way, to the space station, versus what the shuttle had, that should be pretty easy to find out. I've asked some people to do it back of the envelope, it's near a factor of two.

See, I was fortunate because I was serving on the board of directors of, the biggest firm was \$40 billion, the smallest was about \$300 million, firms. I had 14 of those on the New York exchange. On two, one was about \$1.3 to \$1.4 billion and one was about \$350 million. I think I understand commercial. But this isn't commercial, this is subsidized.

It's sad to see how far we've slipped the schedule out, the results we've had, the money we've spent. And, to me, NASA's not doing anything well. Musk had a lot of influence with the Obama Administration. Of course, Obama's no longer there, but Boeing is chugging along. And you know, in Gemini we flew 10 flights in 20 months. And then, in Apollo, after

recovering from the fire, in 11 months we flew five of the giant Saturns and one small Saturn, all 100% success. And, we did it with a regular contract. At times, I get a little bitter when I see this. It's unbelievable. I don't want to be bitter. Now, from your perspective as an ISS leader, are there any issues in the commercial crew program that concern you? You bet there are. They have missed every forecast they had. They have blown up two launch pads and three payloads, and missed their schedule and overrun their cost.

5. What challenges and opportunities does China's ascension as a space power, including its human spaceflight program present for NASA?

Answer: The Chinese really have a wall around them. They want to gather all the technology they can, but I don't see them as the same type of player as Russia. Of course, I've worked with Russia for 40 years. But China, they're a different thing. I think we have to walk very lightly, very slowly, as we go into that relationship. The only way we go in that relationship is to take the lead. By lead, I mean the big booster. I think you can make them a junior partner, that would be my recommendation.

6. From your perspective as leader of the ISS Advisory Committee, are there any issues associated with NASA's commercial crew program that concern you?

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

“NASA: Past, Present, and Future”

Lieutenant General Thomas P. Stafford, Gemini VI, Gemini IX, Apollo 10, Apollo-Soyuz Test
Project Astronaut; Chairman, NASA International Space Station Advisory Committee

Question submitted by Representative Jim Bridenstine, House Committee on Science, Space, and
Technology

1. With the currently planned low launch cadence we should maximize the utility of each SLS launch. Do you think NASA should also look at sending some sort of robotic lander, particularly one of the several that are being developed by commercial entities, on EM-1?

Answer: Absolutely. Over in the appropriations committee, Chairman Culberson is one of our big supporters, and he wants to go to Europa. Theoretically, there's more water on Europa, and with an SLS, you can get out there in about two years, which is unbelievable. But some of these new “commercial” things do not have the boost to push it out there. That's another four or five years afterwards, so I would say, really the more you fly the safer you are. The worst thing you can do is fly and then stand down for two years, and fly again and stand down. But, I think there's a bunch of robotic things that the SLS could launch that could be very effective.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

“NASA: Past, Present, and Future”

Lieutenant General Thomas P. Stafford, Gemini VI, Gemini IX, Apollo 10, Apollo-Soyuz Test
Project Astronaut; Chairman, NASA International Space Station Advisory Committee

Questions submitted by Representative Jim Banks, House Committee on Science, Space, and
Technology

1. From my perspective as a veteran and member of the Armed Services Committee — secure, assured access to space should be a priority as we confront growing challenges around the globe. So, while we often hear that civil space activities are important to our national security, how exactly do you think NASA makes our country safer?

Answer: Absolutely. NASA is a projection of what I call soft power. Apollo was a great example. Everybody knew we were the leader of the world. We'll have the big booster, like the SLS, that we can do robotic missions and human missions on. The DoD has its boosters, the Atlas Vs and the Delta series. I don't know that they need to build that whole Vulcan they're talking about, because I've seen the charts and the Vulcan has about the same payload as the Atlas V. So, why do you need to build a new one?

2. NASA has played a critical role in procuring weather satellites for NOAA to operate. A company (Harris Corp) in my district in Fort Wayne, IN has been making satellite instruments for NASA for 50 years — including many of the instruments used by the U.S. in space today. What should NASA's role be in weather satellites and what is best way to ensure the US doesn't have a gap in weather satellite coverage?

Answer: Well, to me, weather satellites should be the responsibility of NOAA, but NASA should do it in the launch, because they have the expertise. But, NOAA is the customer. They do it for NOAA, and NOAA would maneuver the money over it. I think it would be redundant for NOAA to set up a whole satellite development system when we've got one. But, we would do it to their requirements.

Responses by Dr. Ellen Stofan

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

“NASA: Past, Present, and Future”

Dr. Ellen Stofan, Former NASA Chief Scientist

Question submitted by Chairman Lamar Smith, House Committee on Science, Space, and Technology

1. In your testimony, you had mentioned that super-heavy lift launch vehicles, such as the Space Launch System, could be of immense value to the NASA scientific community in coming years. Would such a capability fundamentally change the way that the science community thinks about future scientific missions and exploration? What kind of changes would such a capability bring to the science community?

Answer: First I would like to thank the Chairman again for having me testify before the Committee on the important issue of NASA’s future direction. Heavy lift launch capability basically cuts in half transit times to the outer solar system. For example, typical trip times to the Saturn system are on the order of 7-8 years, with most utilizing at least one Earth flyby. The SLS cuts that time approximately in half. This results in missions returning data much more quickly, allowing scientists to more rapidly answer scientific questions and then propose and implement follow up missions, greatly increasing the rate and depth of scientific return. Given that we are trying to determine if there is life in the outer solar system, and that we know where to go and what to measure, this rapid pace of data return and follow up will fundamentally change our understanding of life beyond Earth. It is greatly beneficial to students who do not have to wait excessively long periods of time to obtain data to conduct their research. In addition, it reduces mission costs by reducing operations during a long cruise phase.

2. In your written testimony, you state that you “strongly believe it will take Mars astronauts to find indications of life.” Why is it that you think it will take a person, rather than a lander or rover? Are the reasons that in-person presence will be critical to the exploration of Mars extensible to human exploration of other celestial destinations?

Answer: When we are looking for life on Mars, we are most likely looking for fossil evidence of microbes. As a field geologist who has looked for fossils on Earth, I can say with experience that one has to look at a lot of rocks to find what you are looking for. Humans are creative, flexible and fast moving. We can rapidly assess a landscape, visiting multiple rock outcrops in a very short amount of time. We can cover large amounts of territory rapidly, safely and flexibly. None of these things are currently well-developed capabilities in our robotic spacecraft. Mars is uniquely suitable for human exploration given its similarities to Earth. I do not think human presence is as critical at other destinations, such as the Moon, where the geology is much less complex than on Mars, and we are not looking for something so difficult to find as evidence of past life.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

“NASA: Past, Present, and Future”

Dr. Ellen Stofan, Former NASA Chief Scientist

Question submitted by Ranking Member Eddie Bernice Johnson, House Committee on Science, Space, and Technology

1. Commercial space capabilities are growing with multiple new entrants, rapid technological advances, and innovative concepts for potential commercial space services. What key issues and questions should Congress consider in evaluating NASA’s role and relationship with the commercial space sector?
 - a. Is the commercial space sector at a point at which it can operate on a purely “commercial” basis and no longer rely on the government for funding, transportation, or as an anchor tenant user? If not, how involved should the government be in helping to establish or sustain a commercial market?

Answer: I think the key issue for Congress to decide is how much does it want to focus on supporting the development of the commercial space sector that ultimately should have a non-government- supported profit model, versus focusing on NASA’s core mission of science and exploration, where there is no clear profit motive other than the investment in the US technology sector and the past demonstration of benefits from spinoffs. A good example of this is the space telecom industry, which started out wholly government supported, and is now private, and some areas of Earth imaging, which are headed in the same direction.

NASA is currently the anchor tenant in low Earth orbit (LEO). For NASA to be able to change its focus to humans to Mars, the resources NASA spends in LEO must be eventually moved to exploration. NASA has been putting effort into developing the private sector in LEO, and if these efforts continue, hopefully the commercial sector will gradually take over LEO without significant government support through the mid 2020’s allowing NASA to focus on humans to Mars.

I personally believe that NASA’s mission should not be just to support private sector interests, and that the agency has a larger mission of exploration and science. If LEO or other private sector efforts do not turn out to be sustainable, I do not believe it is the government’s role to underwrite the private sector in areas that are not aligned with NASA’s core mission (i.e., resource extraction, space tourism, etc.). Initial support - yes, ongoing anchor role- no.

2. NASA has successfully led numerous international cooperative missions, including several robotic missions and the International Space Station. Unfortunately, budgetary challenges have caused us to withdraw from some partnerships, such as the ExoMars missions with Europe.
 - a. Is it important to maintain NASA's involvement in international cooperative missions in the future, especially as more nations become active in outer space? If so, why?
 - b. What challenges and opportunities does China's ascension as a space power, including its human spaceflight program, present for NASA?

Answer: International cooperation in space is a way to leverage the best minds and ideas from around the world to expand science and further exploration. Missions such as Cassini, the James Webb Space Telescope, and the Global Precipitation Measurement mission are just a few examples of how cooperation between countries enhances scientific return, and combines resources and expertise to expand science. The US needs reliable partners, and it needs to be a reliable partner, especially with Europe, which tends to plan its missions on much longer timescales than the US.

I also believe that space cooperation is an excellent way to partner and build relations with emerging space nations. We see good examples of this with NASA cooperation with the UAE and India. Pursuing knowledge cooperatively in the peaceful exploration of space sends a powerful message on the better side of humanity, and inspires children around the world to pursue the STEM education that helps economies grow.

China is cooperating with all of the other space agencies around the world. Our past space cooperation with the Soviet Union and now Russia show how we can utilize space in soft diplomacy. I believe we overlook an opportunity for enhanced relations with China by not pursuing bilateral space collaboration. We will explore more and gain more knowledge if we cooperate instead of compete.

3. NASA scientists recently narrowed down their list of potential landing sites for the Mars 2020 rover to three candidates. As you know, that mission will extract and cache samples of Martian rock and soil for a future mission to collect and return to Earth where they can be further studied.
 - a. As a field geologist, can you explain the benefits of having humans on Mars to identify and collect science samples? What challenges do humans bring to the search for extant or past life on Mars?
 - b. What if anything needs to be done now to ensure that NASA's Mars planning takes scientific goals such as sample collection into account?

Answer: I do believe humans are necessary to not just find indications of past life on Mars, but the extensive evidence needed to *understand* past life on Mars. Humans are creative, flexible and fast moving. We can rapidly assess a landscape, visiting multiple

rock outcrops in a very short amount of time. We can cover large amounts of territory rapidly, safely and flexibly. None of these things are currently well-developed capabilities in our robotic spacecraft. Mars is uniquely suitable for human exploration given its similarities to Earth. While there are certainly challenges, NASA has already invested a lot of effort into developing advanced life support systems, developing solar electric propulsion that can now be tested for cargo to Mars, done extensive research on radiation, and how to keep humans healthy in microgravity. Entry, descent, landing and ascent (EDLA) remain challenges, and I hope that Congress will support NASA technology development in these areas, so that we can see humans on the martian surface in the 2030's.

In terms of what needs to be done now, I believe that Congress should support return of Mars samples in the 2020's, so that NASA can demonstrate round trip capability, push EDLA technologies, and ensure Mars will be safe for humans. NASA also needs to ensure that its university and internal laboratory facilities are prepared to safely provide top quality analysis of returned Mars samples.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

“NASA: Past, Present, and Future”

Dr. Ellen Stofan, Former NASA Chief Scientist

Question submitted by Representative Bridenstine, House Committee on Science, Space, and Technology

1. In your testimony you touched on an issue that I believe is critically important. Safe integration of UAS into the airspace is going to be key to maximizing the use of our airspace going forward. A recent study pegs the potential economic impact of integration at over 80 billion dollars. Better integration will also ease burdens on the military as they conduct exercises in the airspace. How can President Trump make this more of a national security and economic priority for his Presidency?

Answer: The first ‘A’ in NASA- aeronautics- continues to be critical to the agency and to the nation. NASA Armstrong has been critical in testing and validating algorithms to help safely integrate UAS into the national airspace, and both NASA Ames and Langley have participated in key research to extend the capability of UAS to operate safely and reliably. I hope that President Trump will continue to support, and even expand, NASA’s efforts in UAS, green aviation, future aircraft, supersonic flight, air traffic management research, and hypersonics. All of NASA Aeronautics research underpins the future success of the US aviation industry.

2. What are your thoughts on the opportunities for commercial remote sensing data buys at NASA, particularly in light of NASA’s recent announcement that it might be pursuing a pilot program for Earth science data?

Answer: The capability of commercial space companies in Earth observation to supplement and eventually replace some aspects of NASA and NOAA satellites has been emerging over the last several years, and public-private partnerships can benefit the US taxpayer by enhancing the private sector and potentially reducing costs. NASA investment in small satellite technologies, particularly in the areas of communications, advanced propulsion and instrument technologies will continue to support this emerging area. These data are critical not just for private sector applications, but also for disaster response, weather and climate prediction, and state and local resource management. I believe it will be not just a cost trade, but a ‘where should this critical national capability reside’ decision for Congress to weigh as private sector capabilities continue to expand in this area in the coming decade.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

“NASA: Past, Present, and Future”

Dr. Ellen Stofan, Former NASA Chief Scientist

Question submitted by Representative Crist, House Committee on Science, Space, and Technology

1. Thank you for your testimony today about the importance of NASA’s science programs. I don’t think people always recognize the value this type of research has. Could you tell me a bit more about how NASA’s Earth science programs work, particularly as they relate to improving weather predictions and disaster response?

Answer: NASA utilizes satellites, the ISS and airborne platforms to monitor our complex planet, studying our atmosphere, oceans, and land surfaces. NASA instruments utilize a broad range of the electromagnetic spectrum to give us a comprehensive set of ‘eyes’ to monitor and predict a broad range of Earth processes. NASA conducts fundamental research to better understand weather and climate, understand destructive earth processes such as volcanoes, earthquakes and tsunamis, and monitor the effects of humans on this planet, such as deforestation, changes in land use, and oil spills. NASA data is used extensively for agriculture, from monitoring crop health under GEOGLAM to helping farmers make practical decisions about water use. In the area of disaster response, NASA works with the US Geological Survey, NOAA, and the Department of Homeland Security to provide spacecraft and airborne imagery and data analysis in the event of disasters for use by first responders. NASA has instruments that can identify landslides, damage following tsunamis or earthquakes, and identify and recover from human-induced issues such as oil spills or groundwater depletion. NASA data help monitor flooding and wildfires. NASA research into the development of severe weather, including severe rainfall events, hurricanes and drought, are aiding better prediction of these events, which saves can save lives. For example, NASA’s recent Hurricane and Severe Storm Sentinel (HS3) mission using UAS flew for three hurricane seasons in the Atlantic to better understand the processes that lead to the development and intensification of hurricanes. NASA Earth observation helps all of us in our every day lives, and even creates *downstream* value for our economy as it is used by an emerging array of companies.

2. In your testimony you mentioned that NASA has developed a system to process satellite data and track water use. Can you tell me more about this system and how it specifically benefits Florida?

Answer: Water is a critical natural resource, and in most states, the bulk of water is used by agriculture. Knowing how much water is being used is critical for state and local water officials to manage water supplies. In my testimony, I described a new NASA application called EEFLUX, developed by scientists at the University of Nebraska, with partners at Google Inc., the University of Idaho and the Desert Research Institute, based on METRIC technology, which will allow anyone in the world to produce field-scale maps of water consumption. METRIC is a tool that processes satellite images to make digital maps of water consumption, and is currently being used by water managers in 15 states, including Florida, to track agricultural water use. The exciting thing about the new EEFLUX app is that these data can go directly to farmers, allowing them to check water-use maps in near real-time on a mobile device.

During the California drought, NASA data was also used to track fields left fallow, again allowing water managers to better predict and allocate water supplies. Another project, the NASA Satellite Irrigation Management Support (SIMS) worked with commercial growers and water managers across California to develop new information products from NASA and USGS satellite data (<https://c3.nasa.gov/water/projects/1/>). NASA and the California Department of Water Resources (CDWR) applied space-based data, weather data, and supercomputing resources to map crop water requirements in California, with field trials and demonstration projects with agricultural partners. Results to date for some crops confirmed savings in applied irrigation of 20-40% , along with reductions in nitrate leaching.

In a recent study, Mecikalski et al. (2011, DOI: 10.5772/14478), showed the benefit of using satellite data in developing a comprehensive, uniform map of evapotranspiration (critical for estimates of water use and planning) for Florida. The new EEFLUX tool takes this to the next level, putting these data in the hands of farmers and local water use managers.

Responses by Mr. Tom Young

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

“NASA: Past, Present, and Future”

Mr. Tom Young, Past Director, Goddard Spaceflight Center, Past President/COO, Martin Marietta; Past Chairman, SAIC

Question submitted by Chairman Lamar Smith, House Committee on Science, Space, and Technology

1. You spoke about NASA’s “consistency of capability” as well as industry’s “implementation capability.” What are good ways to combine these two complementary strengths to achieve common space exploration goals? What lessons does the decision to increase involvement of commercial partners on ISS cargo and crew missions have for future hybrid public-private strategies for exploration?

Answer: NASA has been continuously involved in human spaceflight since the initiation of the Mercury Program in 1958, a period of almost six decades. NASA's human spaceflight activity has included Mercury, Gemini, Apollo, Skylab, Saturn, Space Shuttle, International Space Station, SLS and Orion. NASA has experienced incredible successes and some disappointing failures. As a result of this six decades of involvement NASA has developed extraordinary experience, knowledge and expertise in the conduct of human spaceflight activities, largely resident in the people of NASA. This enormous bank of capability can be referred to as "continuity of expertise."

Each of the U.S. human spaceflight projects have involved the aerospace industry. The industry has the capability to design, build, test and operate incredibly complicated and challenging space systems. This exceptional capability can be referred to as "implementation capability."

For all the human spaceflight projects discussed, NASA leadership, authority, direction and capability have been fully utilized. Each project has also used the implementation capability of the aerospace industry to make the project a reality. I believe the utilization of NASA's continuity of expertise in combination with the industry's implementation capability is key to maximizing the probability of success of an endeavor that is so inherently risky.

In my view commercial cargo and commercial crew are being managed significantly different than the past human spaceflight projects. NASA's role in commercial cargo and crew is more oversight than the previous significant direct involvement. Authority, responsibility, decision making, mission trades and mission assurance that were previously included in the NASA charter are largely delegated to the respective contractor.

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

catastrophic consequences. It allows a management approach that relies heavily on the contractor with modest NASA involvement.

In my view, applying the commercial cargo management concept to commercial crew is a serious mistake with potential catastrophic consequences. It is inconceivable to me that applying less than NASA's full continuity of expertise to a program involving the lives of U.S. astronauts would be acceptable or allowed. As an example, Space X has demonstrated implementation capability that deserves respect, but has no human space flight experience.

I strongly believe the choice of management concept for human spaceflight endeavors should depend on the nature of the program and the willingness of NASA to accept risk. For endeavors involving the lives of U.S. astronauts the management concept should require that the full capabilities of NASA and industry be applied with NASA leadership and authority. Nothing less should be acceptable or allowed.

2. You have also stated that, in your view, NASA should seek to limit or eliminate its financial support for activities in low-Earth orbit, restricting its support to purely technical assistance. What should NASA do with the ISS past 2024, and how would that impact deep space exploration capabilities?

Answer: The current NASA budget includes approximately 9B\$ for human spaceflight. About half of the current budget is allocated to Low Earth Orbit (LEO) endeavors which consist of the International Space Station, commercial cargo and commercial crew. The other half of the budget is for human exploration which includes SLS and Orion. There is discussion of NASA leading or being the catalyst for commercializing LEO. Also, there are plans for a cislunar space endeavor of approximately a decade duration. Debate continues as to whether the moon or Mars should be the exploration objective. My very rough estimate is that the human spaceflight budget is under funded by about 10B\$ if no change of scope is implemented and we do everything cited above. Another alternative is we keep the scope defined above and maintain the 9B\$ budget with the result that 90B\$ is spent over the next decade with little progress on a mission to the moon or Mars.

Assuming an approximately 9B\$ budget is most probable, the only credible action is to decide whether the U.S. human spaceflight program is a LEO focused program with no exploration or an exploration program with no LEO program. I believe an exploration program is in the best interest of the U.S. and NASA should cease LEO activities as soon as practical. LEO commercialization should become the responsibility of the private sector with only NASA technical support. This means terminating NASA involvement in the ISS in 2024 or potentially earlier. Possible future responsibility for ISS could be commercial or international partner entities. The important decision is that NASA obtain any information needed for a moon or Mars mission from operations on the ISS as soon as possible, followed by termination of all funding and management responsibility. If no commercial or

international partner is available, the "ISS lights should be turned off" so the U.S. can pursue a credible human exploration program.

3. What kinds of basic infrastructure could the US provide—in space, or on other celestial bodies—that would be most beneficial to future human exploration and utilization of the Moon, Mars, or other destinations? Would infrastructure such as navigation beacons or communications hardware help enable further human and robotic exploration?

Answer: The most important infrastructure the U.S. can provide for future human or robotic exploration is communications.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

“NASA: Past, Present, and Future”

Mr. Tom Young, Past Director, Goddard Spaceflight Center, Past President/COO, Martin Marietta; Past Chairman, SAIC

Question submitted by Ranking Member Eddie Bernice Johnson, House Committee on Science, Space, and Technology

1. In your prepared statement, you stated that *“there are too many potential paths competing for the available resources making it imperative that difficult program decisions be made”* and expressed that failure to decide between competing options *“will result in spending significant resources and not having a credible exploration program”*. One of the competing options you cite as an example deals with NASA’s involvement in low Earth orbit (LEO), specifically whether NASA should lead or be the catalyst for commercializing LEO. In terms of turning LEO over to the commercial space sector, is there sufficient “demand” for purely commercial activities in low-Earth orbit? If not, how involved, if at all, should the government be in helping to establish a commercial LEO market?
 - a. Do you see any long-term requirement for NASA to be a “user” of low-Earth orbit platforms or laboratories?
 - b. What key issues and questions should Congress consider in evaluating NASA’s role and relationship with the commercial space sector?

Answer: I question if there is sufficient "demand" for purely commercial activities in LEO. Hopefully, I am wrong. I believe that it is appropriate for the government to "kick start" an endeavor that is in the national interest. I believe commercializing LEO is such an endeavor; however, I do not believe NASA is the appropriate government organization to lead the commercialization effort. This is certainly not a NASA expertise. For this reason, I believe NASA's involvement should be limited to technical assistance. NASA can certainly be a user of a commercial capability if a peer reviewed process determines it to be the best available response to NASA needs.

Commercial cargo is a good example of a positive relationship between NASA and a commercial provider. NASA receives a needed service. NASA has structured a conservative commercial cargo capability that allows appropriate risk of a mission failure without having catastrophic consequences. Industry receives funding to develop a commercial capability and valuable experience. NASA receives a "Delta 2" class launch capability for other programs. In my opinion, commercial crew is an example of a commercialization endeavor that is a serious mistake for the reasons given in the answer to Chairman Smith's question 1.

In general, I believe the government and in this case NASA should acquire needed services and capability from the private sector when the private sector solution best meets the needs of NASA. I should note that I also believe a strong and capable NASA is in the national

interest. Maintaining a "world class" NASA requires that NASA have "hands on experience" in bringing systems such as Mars rovers, SLS and other robotic spacecraft to reality.

2. NASA has successfully led numerous international cooperative missions, including several robotic missions and the International Space Station. Unfortunately, budgetary challenges have caused us to withdraw from some partnerships, such as the ExoMars missions with Europe.
 - a. Is it important to maintain NASA's involvement in international cooperative missions in the future, especially as more nations become active in outer space? If so, why?
 - b. What challenges and opportunities does China's ascension as a space power, including its human spaceflight program, present for NASA?

Answer: I believe international partnerships are important. International partnerships allow the pooling of capabilities to accomplish challenging missions, allow the pooling of resources to accomplish missions that may not be affordable by a single nation and can be a useful tool in beneficial international relations. Maintaining commitments in international partnerships is most important; however, extreme circumstances may make keeping a commitment impractical. Structuring international partnerships that minimize the impact of a change in commitment should be a goal.

China is clearly a major issue. China's ascension as a space power is a national security issue and any interaction with China must recognize this national security reality. The space cooperative relationships established between the U.S. and the USSR during the "Cold War" demonstrate that a space relationship can be constructive between potential adversaries even in an environment of significant differences. I believe it can be in the U.S. national interest and the national interest of China to explore the possibility of establishing a space cooperative relationship.

Appendix II

ADDITIONAL MATERIAL FOR THE RECORD

STATEMENT SUBMITTED BY REPRESENTATIVE NEAL P. DUNN

Mr. Dunn Opening Statement
NASA: Past, Present, and Future

WASHINGTON - U.S. Rep. Neal Dunn (R-Florida), chairman of the U.S. House Science, Space, and Technology Committee, delivered the following opening statement today at the hearing, *NASA: Past, Present, and Future*. Today's witnesses are **Hon. Harrison Schmitt**, Apollo 17 astronaut; former United States senator; **Lt. Gen. Thomas P. Stafford**, Gemini VI, Gemini IX, Apollo 10, Apollo-Soyuz Test Project astronaut; chairman, NASA International Space Station Advisory Committee; **Dr. Ellen Stofan**, former chief scientist, NASA; and **Mr. Tom Young**, past director, Goddard Spaceflight Center; past president/COO, Martin Marietta; past chairman, SAIC.

As prepared for delivery:

NASA has a storied past. The witnesses before us today are proof of that.

"I echo Dr. Babin's comments that the opportunity to listen to all of you is a special honor.

On a personal note – it is a special honor for me to see Dr. Schmidt and General Stafford, again. Many years ago when I was in high school, my father was associated with NASA through his role with the Science Council. My brother and I were awestruck youngsters who were often underfoot and in the way.

To us, you were rock stars, and sirs, you still are.

I was fortunate enough to be assigned to this committee after serving on the Space Florida Board of Directors the three years prior.

Space Florida now operates and manages many of the assets on Cape Canaveral - the assembly facilities, space launch complexes, satellites, rockets, and shuttle landing strip. And, we launch orbital missions with frequency, which places it among the world's busiest Spaceports.

Importantly, we operate in the black.

To any detractors – I am sure there are none here in this audience – space exploration is noble, aspirational, and inspirational. But, it is also good business. Important to the national and world economies, with over a \$300 billion impact to world economy in 2015.

So while I am still a starry eyed kid when it comes to Space Exploration. I have a keen interest in the commercial market around space.

My question is: What role should NASA play in this? And also, what role should Congress play?"

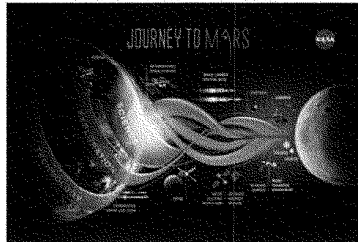
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SCIENCE

Is NASA ready for a human mission to Mars? No, say government auditors.

NASA has a bold vision for a crewed mission to Mars, but thus far, that vision lacks a certain degree of clarity, critics and auditors say.

By **Joseph Dussault**, Staff / August 2, 2016

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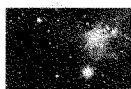
Courtesy of NASA

NASA has taken bold steps toward crewed Mars exploration in recent years. But according to a new audit, the agency may be moving too hastily.

The Government Accountability Office (GAO) expressed concerns this past week about the feasibility of NASA's Orion crew capsule and Space Launch System (SLS). In two government-requested audits, the GAO questioned NASA's ability to meet program deadlines, citing insufficient funding and internal management issues.

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“The main problem is that we do not have a clear long-term goal for the national human spaceflight program,” says Mike Gruntman, a professor of astronautics at the University of Southern California, in an email to The Christian Science Monitor. “Being rudderless does not help in bringing public excitement and support.”



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NASA’s “Journey to Mars” initiative has been a source of both excitement and controversy. The Asteroid Redirect Mission, in which the agency will send four astronauts to redirect an asteroid into the moon’s orbit, is slated to launch sometime in the next decade. The mission is designed to test new propulsion technology for future crewed Mars missions. In the 2030s, NASA hopes to send an Orion crew to the red planet.

NASA plans to complete the first SLS launch in 2018. In the test mission, called Exploration Mission 1, the rocket will carry an empty Orion into orbit around the moon. In subsequent missions, SLS/Orion will launch with a full crew. NASA has scheduled Exploration Mission 2 for April 2023, but administrators hope to launch as early as 2021.

According to the GAO, however, the agency’s schedule just isn’t realistic. By pushing for earlier launch dates, NASA is increasing the inherent risk of a deep space mission. NASA’s budgeting practices are also scrutinized in GAO’s audit. In September, the agency asked for \$11.3 billion to prepare Orion for launch.

“Ideally, if these programs go forward, NASA would be taking actions to reduce the risks we see now, which are being caused by management issues,” says Cristina Chaplain, who led the GOA audit, in an interview with the Monitor. “They’re going to face the technical issues no matter what. But they’re exacerbating them with management concerns, like not having accurate cost estimates.”

In February, the US House Committee on Science, Space, and Technology convened to discuss NASA’s long-term goals. Members argued that the agency lacked clear direction

when it came to Mars exploration. The committee, which is composed mostly of Republican congressmen, also raised concern about the cost of a crewed Mars mission.

When the cold war was in full swing, competition with the Soviet Union was an effective motivation for US space travel. As a result, the Apollo missions and other subsequent programs met little resistance in terms of funding and public support. By comparison, today's Congress has been critical of NASA's more ambitious initiatives over the last few decades.

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In some ways, the glory days of Apollo-era space travel are over. But in other ways, NASA is simply facing the same challenges it always has.

"By the middle of the '60s, Congress is already growing very restive at spending billions of dollars on the Apollo program when there are very profound problems down here on Earth," says Peter Westwick, a Space Age historian at the University of Southern California, in a phone interview with the Monitor. "NASA has always faced this problem: How do you justify spending a lot of money to explore space?"

According to some experts, the US space program was politicized from the outset — and that's the way it should be.

"Yes, there's the counter-argument that the NASA budget is just a fraction of a percent of the federal budget," Professor Westwick says. "But when you're talking about billions of dollars, then it becomes not just a technical decision, but a political decision as well."

But Chaplain isn't concerned with the politics of space travel. It's not that NASA's plans for Mars exploration are premature, she says, just that clearer direction will be essential going forward.

"First of all, we need a clear sense of where we're going and when," Chaplain says. "We don't have that from the administration or Congress. There's no, 'Hey, we're going to the moon in 10 years.' We need that kind of goal set, and then we can decide if the path we're on is the right one."

"We don't even know what the path is at this point," she adds. "All we have are these two programs that represent the beginning of something that will eventually lead to a long-term effort."

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FIRST LOOK

