THE LEGACY OF APOLLO

HEARING

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

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C O N T E N T S

July 16, 2019

THE LEGACY OF APOLLO

TUESDAY, JULY 16, 2019

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

The Committee met, pursuant to notice, at 10:05 a.m., in room 2318 of the Rayburn House Office Building, Hon. Eddie Bernice Johnson [Chairwoman of the Committee] presiding.

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

HEARING CHARTER

"The Legacy of Apollo"

Tuesday, July 16, 2019
10:00 AM
2318 Rayburn House Office Building

PURPOSE

The purpose of the hearing is to commemorate the 50th anniversary of the Apollo 11 Moon landing.

WITNESSES

- **Mr. Charles Fishman,** author of *One Giant Leap: The Impossible Mission That Flew Us to the Moon*[1]
- **Dr. David W. Miller,** Vice President and Chief Technology Officer, The Aerospace Corporation
- **Dr. Peter Jakab,** Chief Curator, Smithsonian Air and Space Museum

OVERARCHING QUESTIONS

- *What events and factors led to the decision to pursue the Moon landing and the Apollo program?*
- *What is the legacy of Apollo?*
- *What scientific and technological advancements did the Apollo program enable?*

BACKGROUND

On October 4, 1957, the Soviet Union launched Sputnik 1, humanity's first artificial satellite. The Soviets followed Sputnik 1 by launching the first animal, a dog named Laika, into space on board Sputnik 2. The United States launched its first satellite, Explorer I, on January 31, 1958, which contained scientific instrumentation and led to the discovery of the Van Allen radiation belts. The "Space Race" had begun. Later in 1958, Congress passed, and President Eisenhower signed, the National Aeronautics and Space Act, establishing the National Aeronautics and Space Administration (NASA) from the National Advisory Committee for Aeronautics.[2]

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[1] Charles Fishman, *One Giant Leap: The Impossible Mission That Flew Us to the Moon*, Simon and Schuster, 2019.
[2] Pub. L. No. 85-568, "National Aeronautics and Space Act of 1958," July 29, 1958.

In 1959, the Soviet Union sent the first ever spacecraft to the Moon, Luna 2. This was followed by several successes in human spaceflight, most notably launching the first human to space and into orbit, Yuri Gagarin, on April 12, 1961. Less than a month later, the U.S. launched Alan Shepard into space on a suborbital trajectory as part of Project Mercury. In 1962, John Glenn became the first American to orbit Earth. The Soviet Union also launched the first woman into space, Valentina Tereshkova, on June 16, 1963.

Fearful that that Soviet Union would lead in space, President John F. Kennedy proposed in a speech to Congress on May 25, 1961, that the U.S. *"should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth."*[3] President Kennedy followed this with a speech in September of 1962 at Rice University in Texas, stating:[4]

> *"There is no strife, no prejudice, no national conflict in outer space as yet. Its hazards are hostile to us all. Its conquest deserves the best of all mankind, and its opportunity for peaceful cooperation may never come again. But why, some say, the Moon? Why choose this as our goal? And they may well ask, why climb the highest mountain? Why, 35 years ago, fly the Atlantic? Why does Rice play Texas?*
>
> *We choose to go to the Moon! 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."*

Project Gemini succeeded the Project Mercury program. Gemini had four main goals: *"to test an astronaut's ability to fly long-duration missions (up to two weeks in space); to understand how spacecraft could rendezvous and dock in orbit around the Earth and the moon; to perfect re-entry and landing methods; and to further understand the effects of longer space flights on astronauts."*[5] Ten crewed missions in all were flown as part of Project Gemini, allowing the U.S. to surpass the Soviet Union in the Space Race. President Kennedy's challenge would be met in the next phase, Project Apollo.

Project Apollo

The Apollo program followed the successful completion of Project Gemini with a tragic failure. A fire during an Apollo 1 ground test resulted in the deaths of astronauts Virgil "Gus" Grissom, Edward White, and Roger Chaffee. A nearly two-year hiatus in crewed American spaceflights followed. Apollo 4, an uncrewed flight, successfully demonstrated the power of the Saturn V

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[3] President John F. Kennedy, "Special Message to Congress on Urgent National Needs", President John F. Kennedy Presidential Library and Museum, May 25, 1961.
[4] President John f. Kennedy, "Text of President John Kennedy's Rice Stadium Moon Speech", https://er.jsc.nasa.gov/seh/ricetalk.htm, accessed July 15, 2019.
[5] NASA, "Gemini", https://www.nasa.gov/mission_pages/gemini/index.html, accessed July 12, 2019.

rocket. Apollo 7 returned astronauts to space. Apollo 8 sent the first crewed spacecraft to the Moon, where it orbited ten times. Apollo 9 tested the lunar lander module in Earth orbit, including rendezvous and docking. Apollo 10 was a test run for the first Moon landing. The lunar module got as close as 50,000 feet to the lunar surface and performed rendezvous and docking in lunar orbit.

On July 16, 1969 at 9:32 a.m. EDT, Apollo 11 was launched from Kennedy Space Center in Florida with astronauts Neil Armstrong as commander, Edwin "Buzz" Aldrin as lunar module pilot, and Michael Collins as command module pilot. Three days later, Apollo 11 reached lunar orbit. After surveying prospective landing spots, the lunar module containing Armstrong and Aldrin separated from the command module, while Collins stayed behind in the command module. The lunar module, piloted by Armstrong, landed at 4:17 p.m. EDT on July 20. Armstrong indicated their success by telling mission control, *"Houston, Tranquility Base here. The Eagle has landed."*

At 10:56:15 p.m. EDT, July 20, 1969, Neil Armstrong became the first human to set foot on the Moon, saying, *"That's one small step for [a] man, one giant leap for mankind."*[6] Buzz Aldrin soon joined him on the surface. Over the course of the next two hours, Armstrong and Aldrin collected 22 kilograms of lunar rocks and dust,[7] deployed multiple scientific experiments, including a seismometer and a retroreflector, and planted the American flag. The two astronauts spent nearly 22 hours on the surface of the Moon before launching back into lunar orbit to dock with the command module, piloted by Collins. At 12:50 p.m. EDT on July 24, they splashed down safely in the Pacific Ocean.

NASA launched six more Apollo missions; five successfully reaching different locations on the Moon's surface. Apollo 13 experienced a major failure when an oxygen tank exploded, but the crew, in collaboration with mission control and ground crew, managed to work around multiple constraints to bring the Apollo 13 crew safely back to Earth. The astronauts on each successive, successful Apollo mission carried out longer Moon walks and performed more scientific experiments than the previous ones. Apollo 15, 16, and 17 astronauts drove the Lunar Roving Vehicle on the surface to explore farther and collect a more diverse set of lunar rocks and dusts. In total, Apollo astronauts brought back 382 kilograms of lunar material to be used mostly for scientific purposes, but also as goodwill gifts to states and foreign heads of state.

In 1973, NASA reported the cost of the Apollo program to be $25.4 billion, which has been estimated to be around $260 billion in FY 2019 dollars, according to a June 17, 2019, article from *The Space Review*.[8] That article also reanalyzes the costs of the Apollo program and estimates the total lunar effort to have actually been $288 billion in FY 2019 dollars. More than 400,000 people worked on Apollo either directly or through contracts.[9]

[6] NASA, "Apollo 11 Timeline", https://history.nasa.gov/SP-4029/Apollo_11i_Timeline.htm, accessed July 12, 2019.
[7] Universities Space Research Association, "Apollo 11 Mission", https://www.lpi.usra.edu/lunar/missions/apollo/apollo_11/samples/, accessed July 12, 2019.
[8] Casey Dreier, "A new accounting for Apollo: how much did it really cost?", *The Space Review*, June 17, 2019.
[9] NASA, "NASA Langley Research Center's Contributions to the Apollo Program", https://www.nasa.gov/centers/langley/news/factsheets/Apollo.html, accessed July 12, 2019.

Geopolitical Impacts

The successful Apollo 11 Moon landing and the subsequent Apollo Moon landings are largely viewed as the culmination of the Space Race.[10] It symbolized American power and prestige. A U.S. survey of foreign public opinion found that the rest of the world viewed the Apollo 11 Moon landing as "an achievement of all mankind," that it "should serve to bring mankind closer together," and that it led to a "high degree of personal identification with the United States" due to the very open, public nature of the event.[11] Indeed, messages from 73 world leaders were left on the Moon in a silicon disc by the Apollo 11 astronauts.[12] After landing, the three astronauts went on a 24-nation world tour,[13] where they were greeted by hundreds of thousands to even millions of people at each event.[14] President Nixon used the success of Apollo 11 to land a meeting with Romanian President Ceauşescu, who passed along messages to China and Vietnam. This later led to normalization of relations between the U.S. and China and North Vietnam.[11]

Soon after the Apollo 11 Moon landing, the Soviet program to land people on the Moon ended. In 1975, the last Apollo mission, the Apollo-Soyuz Test Project, entailed a joint U.S.-Soviet mission in which an Apollo command/service module docked with a Soviet Soyuz capsule, formally ending the Space Race. This began the first of many collaborative efforts between the United States and the Soviet Union (and now Russia) in space exploration.[15]

Research and Development Impacts

The Apollo Moon landing, watched on television by hundreds of millions of people, was recorded using the lens of a compact camera specifically built for space, and "Moon Boot" material greatly improved both shock absorption and stability in athletic footwear.[16] These are just two of the many new technologies that had to be developed specifically for the Apollo missions. Many of these technologies were spun off into commercial projects. The Space Foundation's Space Technology Hall of Fame has inducted 11 technologies from Apollo, including cordless tools, liquid-cooled garments, an improved fire fighter breathing system, fire-resistant aircraft seats, and anti-shock trousers, among others. [17]

One of the most significant breakthroughs from the Apollo mission was the use of newly invented integrated circuit chips. Today, computer chips are foundational to our technology-

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[10] W. David Compton, *Where No Man Has Gone Before: A History of Apollo Lunar Exploration Missions*, accessed at https://history.nasa.gov/SP-4214/ch1-1.html on July 12, 2019.
[11] Teasel Muir-Harmony, "American Foreign Policy and the Space Race", https://doi.org/10.1093/acrefore/9780199329175.013.27, accessed July 12, 2019.
[12] NASA, "Apollo 11 Goodwill Messages", https://history.nasa.gov/ap11-35ann/goodwill/Apollo_11_material.pdf, accessed July 12, 2019.
[13] Smithsonian Air and Space Museum, "Apollo World Tour", https://airandspace.si.edu/multimedia-gallery/7332hjpg, accessed July 12, 2019.
[14] Chabeli Herrera, "How Apollo 11 dazzled the world: Moon maps in the Netherlands and American flags in Japan", *Orlando Sentinel*, June 23, 2019
[15] Richard J. Samuels, *Encyclopedia of United States National Security*, SAGE Publications, Dec 21, 2005.
[16] NASA, "Benefits from Apollo: Giant Leaps in Technology", accessed at https://www.nasa.gov/sites/default/files/80660main_ApolloFS.pdf, July 2004.
[17] Space Foundation, "Space Technology Hall of Fame", https://www.spacefoundation.org/what-we-do/space-technology-hall-fame, accessed July 12, 2019.

driven society. In the early 1960s, however, the chip was had not yet been tested, and its dependability was largely unknown. Despite some initial concerns, NASA used chips supplied by MIT in the Command/Service and Lunar Modules.[18] NASA's willingness to deploy a new, innovative technology on such a high-profile, dangerous mission helped launch the computer age.[19]

The Apollo program enabled groundbreaking science, the legacy of which has a lasting impact today. One of the greatest scientific legacies of Apollo has resulted from the analysis of some of the 382 kilograms of lunar rock and soil samples returned to Earth. Unopened samples from Apollo are still being allocated to researchers, which has led to breakthroughs about the history of the Moon and the Solar System.[20] The Apollo missions also enabled various geophysical investigations using seismology, surface gravimetry and magnetometry, heat-flow measurements and the deployment of laser reflectors used to measure the distance to and on the moon.[21] Results from Apollo have informed scientists' understanding of water on the Moon,[22] the origin of the Moon,[23] and the origin of our own planet Earth.[24]

Cultural Impacts

The Apollo 11 mission was a global event. An estimated one million spectators watched the launch of Apollo 11 in person, including President Johnson, Vice President Agnew, 19 governors, 200 Congressmen, and 60 ambassadors, and another 25 million Americans watched on live TV, which was also broadcast to 33 other countries around the world on six continents.[25] NASA estimates that 650 million people watched Armstrong step onto the lunar surface, about 18 percent of the world population at the time, while the Voice of America broadcast it over radio in 36 languages to another estimated 750 million people.[26]

Historians credit the Apollo program with helping inspire a new wave of environmentalism,[27] particularly by the Apollo 8 *Earthrise* photo and the Apollo 17 *The Blue Marble* photo. The first Earth Day took place less than a year after the first Moon landing in 1970. That same year,

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[18] Paul Ceruzzi, "Apollo Guidance Computer and the First Silicon Chips", Smithsonian National Air and Space Museum, October 14, 2015.
[19] Sharon Gaudin, "NASA's Apollo technology has changed history", *Computer World*, July 20, 2009.
[20] NASA, "NASA Selects Teams to Study Untouched Moon Samples", https://www.nasa.gov/feature/nasa-selects-teams-to-study-untouched-moon-samples, March 11, 2019.
[21] Ian A. Crawford, *Astronomy & Geophysics*, Volume 53, Issue 6, pp. 6.24-6.28, December 2012.
[22] Freeman, J.W., Jr., H.K. Hills., R.A. Lindeman, and R.R. Vondrak, "Observations of Water Vapor at the Lunar Surface", *The Moon*, 8, 115–128, 1973
[23] U. Weichert, et al. "Oxygen Isotopes and the Moon-Forming Giant Impact", *Science*, 294, 345, 2001.
[24] Ron Cowen, "Common source for Earth and Moon water", *Nature*, May 9, 2013.
[25] Charles D. Benson William Barnaby Faherty, *Moonport: A History of Apollo Launch Facilities and Operations*, The NASA History Series, 1978.
[26] NASA, "Apollo 11 Mission Overview", https://www.nasa.gov/mission_pages/apollo/missions/apollo11.html, accessed July 12, 2019.
[27] Andrew Chaikin, "Live from the Moon: The Societal Impact of Apollo", *Societal Impact of Spaceflight*, accessed at https://history.nasa.gov/sp4801-chapter4.pdf on July 12, 2019.

President Nixon created the Environmental Protection Agency, which is widely considered an indirect result of Apollo.[28]

NASA's space program inspired a new generation to go into science, technology, engineering, and math (STEM) fields. During the 1960s, the number of PhDs graduating from American universities tripled, with a particularly strong increase in the field of physics.[29]

At the time, however, the Apollo program did not enjoy universal support from the American people. A 2003 study by former NASA Chief Historian Roger Launius found that, throughout the 1960s, polls showed that "a majority of Americans did not believe Apollo was worth the cost, with the one exception to this a poll taken at the time of the Apollo 11 lunar landing in July 1969."[30] This view was echoed by a number of Members of Congress and other opinion leaders, given the other national demands on scarce resources, including the Vietnam War and other Great Society initiatives.

There was also criticism from civil rights activists who saw the funding required for the space program as money that could have been better spent improving the lives of minorities. A *New York Times* article from July 27, 1969, just days after the first Moon landing, was entitled "Blacks and Apollo: Most Could Have Cared Less."[31] Additionally, few women and people of color were part of the program, although there were trailblazers like Margaret Hamilton, JoAnn Morgan, and Poppy Northcutt. The role of Black women in particular in Apollo remained largely hidden for decades, although their critical contributions are now beginning to become more widely known, such as the "Hidden Figures" (Katherine Johnson, Dorothy Vaughan, and Mary Jackson).[32]

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[28] Moira McGuinness, "Science Wednesday: Earthrise – The Picture That Inspired the Environmental Movement", https://blog.epa.gov/2009/07/01/science-wednesday-earthrise/, July 1, 2019.
[29] Christopher Riley, "Apollo 40 years on: how the moon missions changed the world for ever", *The Guardian*, December 15, 2012.
[30] Roger D. Launius, "Public opinion polls and perceptions of US human spaceflight", *Space Policy*, 19, pp 163-175, 2003.
[31] Thomas A. Johnson, "Blacks and Apollo: Most Could Have Cared Less", *New York Times*, July 27, 1969.
[32] Margot Lee Shetterly, *Hidden Figures*, William Morrow and Company, 2016.

Chairwoman JOHNSON. The hearing will come to order. And without objection, the Chair is authorized to declare recess at any time.

Good morning, and welcome to today's hearing on "The Legacy of Apollo." I want to thank each of our distinguished witnesses for their participation, and I look forward to your testimony.

As some of you may know, today really is the 50th anniversary of the launch of Apollo 11, and this hearing is starting about the time the three astronauts reached Earth's orbit before landing on the Moon. It is fitting that we hold this hearing. Our Committee was established in direct response to the challenge of Sputnik, and our predecessors on this Committee played an important role in authorizing and maintaining support for the Apollo program.

What is the legacy of Apollo? It is a question to which there has been multiplicity of responses over the years, and our witnesses will be offering their own thoughtful perspectives for our consideration.

As the 50th anniversary of the Moon landing approach has drawn closer, there have been numerous stories and historical anecdotes that have captured the media's attention, which is a testimony to the enduring fascination Americans have with this unique moment in our history. Each of these stories have shone a light on different aspects of the Apollo program's impact, whether it be something as specific as helping speed the development of widespread use of integrated circuits, to something as broad as the positive geopolitical image that the United States gained aftermath of the Apollo 11 landing.

To me, these are all important legacies of Apollo. But I think there are also more intangible impacts that need to be recognized when we think of Apollo. Namely, there is the often-cited inspirational value that Apollo and our space program overall has had on inspiring a generation to seek careers in STEM (science, technology, engineering, and mathematics) fields. They may not have wound up working at NASA, but they made meaningful contributions across a range of disciplines in the following decades.

And most fundamentally, there is the proof that the Apollo program offered this Nation is capable of great accomplishments when we share a common goal and a willingness to commit the resources needed to achieve it.

Apollo was a unique accomplishment at a unique time in our Nation's history. We should take great pride in it, but we should also take it as a demonstration of what we are capable of doing as a Nation. If we work together to harness the spirit and inspiration of Apollo to address the other daunting challenges that we face as Americans, that may be the best and most consequential Apollo legacies of this generation.

[The prepared statement of Chairwoman Johnson follows:]

Good morning, and welcome to today's hearing on "The Legacy of Apollo." I want to thank each of our distinguished witnesses for their participation, and I look forward to your testimony.

As some of you may know, today is the 50th anniversary of the launch of Apollo 11, and this hearing is starting about the time the three astronauts reached Earth orbit before heading off to the Moon. It is fitting that we hold this hearing. Our Committee was established in direct response to the challenge of Sputnik, and our predecessors on this Committee played an important role in authorizing and maintaining support for the Apollo program.

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Apollo was a unique accomplishment at a unique time in our nation's history. We should take great pride in it, but we should also take it as a demonstration of what we are capable of as a nation. If we will work together to harness the spirit and inspiration of Apollo to address the other daunting challenges that we face as Americans, that may be the best and most consequential of Apollo's legacies to this generation.

I am entering two letters for the record. One is from Margaret Hamilton, who led the team that developed the Apollo on-board flight software for both the Command Module and Lunar Module. The other letter is from the Aerospace Industries Association, an association of aerospace and defense companies. Many of its industry members worked on the Apollo program.

With that, I yield to Ranking Member Lucas for his opening statement.

Chairwoman JOHNSON. I'm entering two letters for the record. One is from Margaret Hamilton, who led the team that developed the Apollo on-board flight software for both the command module and lunar module. The other letter is from the Aerospace Industries Association, an association of aerospace and defense companies. Many of its industry members worked on the Apollo program.

And with that, I yield to Mr. Lucas.

Mr. LUCAS. Thank you, Madam Chair.

In 1969, driven by curiosity, ambition, and an innate urge to explore, Americans landed on the Moon. Doing so at the height of the Cold War helped establish our country's technological supremacy and gave us a fundamental edge over the Soviet Union. The Apollo program's success was far from certain, but our Nation set to achieve the bold goal nonetheless. As Neil Armstrong remarked upon return, the Nation staked its reputation on the mission. What resulted was perhaps the greatest achievement of any organization. This week we celebrate the 50th anniversary of that achievement. This celebration should be accompanied by a renewed resolve to return to the Moon.

Our reasons for returning to the Moon are even stronger than they were 50 years ago. Going back to the Moon isn't a symbolic effort; we need an American presence there to keep us at the forefront of technological development, power our missions to Mars, and ensure American values explore the next frontier in space.

The technological innovations that came from human exploration of the Moon have direct practical applications here on Earth. Technology developed by NASA is now used in everything from infant formula to cell phones. We have precise robotic surgical capacities and safer flights from de-icing chemicals because of NASA innovations.

Developing the technology necessary to establish a human presence on the Moon will have untold applications in the future. For example, significant portions of the Apollo command and service module were built in my home State of Oklahoma. The integrated circuit chips contained in the service module went on to spark the information age. Technological advancements from future lunar exploration can be just as impactful.

Direct study is also critical from a scientific perspective. The Moon can give us a wealth of information about our sun, our Solar System, our planet, giving us a better idea of our place in the universe. The Moon also has exciting potential resources, including rare Earth elements and platinum group metals, helium-3, and, most importantly, water ice which can be converted to fuel and propel future exploration.

With all these benefits, the question isn't whether humans will return to the Moon; the question is whether the United States will lead that effort. We're facing increased international competition, and we can no longer take American leadership in space for granted. China has been very vocal about plans to establish a human base on the Moon. Unlike the U.S., which has a civilian agency overseeing exploration, China's program is managed by the People's Liberation Army.

There are very real reasons to be concerned about China having an advantage over the U.S. from the technological innovations and resource development that will come from returning to the Moon. More importantly, explorers take with them their national values and establish precedent for future activities. I would hope that the Moon and all the cosmos will be explored with the principles of freedom and liberty.

Returning to the Moon won't be easy, however. We are in the process of developing the technological capacities we'll need. Reaching the Moon requires rockets far more powerful than those used to reach the International Space Station (ISS). The Space Launch System (SLS) will be the most powerful rocket built. In concert with the Orion spacecraft, a state-of-the-art crew module—capsule I should say, SLS will allow us to travel to the Moon and, eventually, beyond.

We also need to make progress on new technologies which aren't yet fully funded or developed. The spacesuits we currently use for extravehicular activity outside the ISS do not have the capacities required for use on the Moon. We need to engineer new suits that are compatible with multiple mission requirements. And, of course, we need lunar landers capable of carrying humans. NASA is working with commercial partners to develop these vehicles.

Beyond the technological innovation, however, a return to the Moon requires steadfast, consistent support. It requires a true national commitment, one that doesn't change from year to year or with the political swings. For too long, U.S. space exploration has been plagued by a lack of both a vision and a long-term commitment to see ideas through to execution.

I believe we now have most of the pieces in place to make a return to the Moon possible. Our President and Vice President have a bold goal. NASA has proposed an initial plan that's budget-neutral, technologically feasible, and makes a down payment to send Americans to the Moon by 2024 without jeopardizing other critical missions.

To paraphrase Walter Cronkite, and yes, I watched Walter Cronkite all week long 50 years ago as a little kid, the world bore witness to man's resolve in 1969. A man's dream and a Nation's pledge were fulfilled. The lunar age had begun. It's time to renew that legacy and rekindle that resolve. I yield back, Madam Chair.

[The prepared statement of Mr. Lucas follows:]

In 1969, driven by curiosity, ambition, and an innate urge to explore, Americans landed on the Moon. Doing so at the height of the Cold War helped establish our country's technological supremacy and gave us a fundamental edge over the Soviet Union. The Apollo program's success was far from certain, but our nation set to achieve the bold goal nevertheless. As Neil Armstrong remarked upon return, the nation staked its reputation on the mission. What resulted was perhaps the greatest achievement of any organization. This week we celebrate the 50th anniversary of that achievement. This celebration should be accompanied by a renewed resolve to return to the Moon.

Our reasons for returning to the Moon today are even stronger than they were fifty years ago. Going back to the Moon isn't a symbolic effort: We need an American presence there to keep us at the forefront of technological development, power our missions to Mars, and ensure American values explore the next frontier in space.

The technological innovations that come from human exploration of the Moon have direct practical applications here on Earth. Technology developed by NASA is now used in everything from infant formula to cell phones. We have precise robotic surgical capabilities and safer flights from deicing chemicals because of NASA innovations. Developing the technology necessary to establish a human presence on the Moon will have untold applications in the future. For example, significant portions of the Apollo Command and Service Module were built in my home state of Oklahoma. The integrated circuit chips contained in the service module went on to spark the information age. Technological advancements from future lunar exploration could be just as impactful.

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We also need to make progress on new technologies which aren't yet fully funded or developed. The spacesuits we currently use for extravehicular activity outside the ISS do not have the capabilities required for use on the Moon. We need to engineer new suits that are compatible with multiple mission requirements. And, of course, we need lunar landers capable of carrying humans. NASA is working with commercial partners to develop these vehicles.

Beyond the technological innovation, however, a return to the Moon requires steadfast and consistent support. It requires a true national commitment-one that doesn't change year after year, or with political swings. For too long U.S. space exploration has been plagued by a lack of both a vision and a long-term commitment to see ideas through to execution.

I believe we now have most of the pieces in place to make a return to the Moon possible. Our President and Vice President have a bold goal. NASA has proposed an initial plan that is budget neutral, technically feasible, and makes a down payment to send Americans to the Moon by 2024 without jeopardizing other critical missions.

To paraphrase Walter Cronkite, the world bore witness to man's resolve in 1969. A man's dream and a nation's pledge were fulfilled. The lunar age had begun. Its time to renew that legacy and rekindle that resolve.

Chairwoman JOHNSON. Thank you very much.

If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

[The prepared statement of Ms. Horn follows:]

Good morning, and thank you Madame Chairwoman for holding this hearing on "The Legacy of Apollo". And thank you to our witnesses for being here to share in this momentous anniversary of the Apollo 11 Moon landing.

The Apollo Program and the Apollo 11 mission, including Neil Armstrong, "Buzz" Aldrin, and Michael Collins, represent everything we think of in America's space program-ambition, inspiration, innovation, and discovery.

Apollo astronauts became our national heroes, including Oklahoma's own Apollo hero, Gen. Thomas P. Stafford, who commanded the Apollo 10 mission and the Apollo-Soyuz Test Project, the first international human spaceflight mission. I'll be speaking more about Gen. Stafford and his accomplishments later this week.

The value of the Apollo program is beyond measure. Apollo's inspiring mission attracted countless Americans into science, technology, mathematics, and engineering disciplines. In addition, the program's stringent requirements lead to significant technological advances, many of which were translated into products that have benefited our everyday lives, including cordless tools, heart monitors, and firefighting breathing systems. Fundamentally, the success of Apollo on the world stage contributed significantly to America's global standing, and more.

While the 50th anniversary of Apollo 11 that we are commemorating today was a momentous success, the anniversary also allows us to reflect on what we can learn from the journey to reaching that success, including the resilience gained from overcoming setbacks and failures.

As we celebrate Apollo 11's historic accomplishment, we should remember those who made the ultimate sacrifice in the pursuit of President Kennedy's direction to send American astronauts to the Moon and return them safely.

Those brave individuals included Elliot See, Charles Bassett, and the Apollo 1 crew, Ed White, Virgil "Guss" Grissom, and Roger Chaffee.

Apollo taught us the value of taking audacious and yet intentional risks. NASA's relentless pursuit to mitigate risks, work through test anomalies and failures to understand what went wrong and why, and to take corrective actions in response, became the discipline and culture that defines NASA today.

NASA's intensity and rigor in its technical pursuit to send our astronauts to the Moon and return them safely is captured in a 1970 NASA technical paper, "What Made Apollo a Success?," issued just 1 year after the Apollo 11 landing. The piece concludes that, above all, "attention to detail" was critical to the Apollo 11 success.

A few important examples include:

- "The single most important factor leading to the high degree of reliability of the Apollo spacecraft was the tremendous depth and breadth of the test activity."
- "We considered changes large and small. An example of a large change is the new spacecraft hatch that was incorporated after the fire. However, we reviewed in equal technical detail a relatively small change, such as a small piece of plastic to go inside the astronaut's ballpoint pen."
- "Throughout Apollo, many discrepancies or failures occurred daily. The failure had to be understood and, if applicable, some corrective action taken. This might involve design change, re inspection, or perhaps procedural change."
- "Pete Conrad said that landing his Apollo 12 lunar module, after dust obscured the landing point, was the most difficult task he had ever performed.

It took all of his 20 years of experience as a professional aviator, his previous work on two Gemini flights, his training for Apollo, and his knowledge and confidence in the Apollo spacecraft systems to make that landing a success."

At contractor facilities, an equal degree of drive took place in understanding what went wrong and taking action in response.

Apollo 11's success was built on learning from failure, and if we can pass that lesson to our next generation, we will be continuing one important legacy as we look to achieve America's future goals in sending humans to explore the mysteries of space and other worlds in our Solar System.

Apollo inspired a generation, showed the world what's possible when the nation comes together to focus on an ambitious goal, and, in turn, changed the world in both foreseeable and unforeseeable ways. Through this historic celebration, the legacy of Apollo allows us to learn the lessons that can guide our pursuits to the Moon and our journey on to Mars.

Thank you, and I yield back.

Chairwoman JOHNSON. At this time, I'd like to introduce our witnesses. Our first witness is Mr. Charles Fishman and a journalist. And thank you for your efforts. The author of "One Giant Leap: The Impossible Mission That Flew Us to the Moon." Fishman is an award-winning reporter, magazine writer, and author who started his career at the Washington Post where he spent 7 months covering the Space Shuttle Challenger accident in 1986. He has been reporting on space ever since for The Atlantic, the Smithsonian, and the Fast Company magazines, his longtime professional home. Mr. Fishman earned a bachelor's degree in social studies from Harvard University. Welcome.

Our second witness is Dr. David Miller, Vice President and Chief Technology Officer of the Aerospace Corporation. Dr. Miller is also a Jerome Hunsaker Professor of Aeronautics and Astronautics at the Massachusetts Institute of Technology (MIT) where he is currently on extended leave of absence to work at the Aerospace Corporation. Previously, Dr. Miller took an extended leave of absence from MIT from 2014 to 2016 to serve as NASA's Chief Technologist. Dr. Miller earned a bachelor's degree, master's degree, and Ph.D. in aeronautics and astronautics, all from MIT.

Our final witness is Dr. Peter Jakab, Chief Curator of the Smithsonian National Air and Space Museum. Formerly, Dr. Jakab served as the museum's Associate Director of Collections and Curatorial Affairs. In addition, Dr. Jakab's previous museum work includes stays at the Edison national historic site in West Orange, New Jersey, and the New Jersey Historical Commission. He also spent a year with the Thomas A. Edison Papers Project and 2 years teaching American history at Rutgers University doing his graduate study. He holds a bachelor's degree, a master's degree, and a Ph.D. in American history from Rutgers. Welcome.

Our witnesses should know you each have 5 minutes for your spoken testimony. Your written testimony will be included in the record of the hearing. And when you all have completed your spoken testimony, we will begin rounds of questions. Each Member will have 5 minutes.

Thank you for being here, and now we'll start with Mr. Fishman.

TESTIMONY OF CHARLES N. FISHMAN, AUTHOR, "ONE GIANT LEAP: THE IMPOSSIBLE MISSION THAT FLEW US TO THE MOON"

Mr. FISHMAN. Thank you. The Soviets launched the first spacecraft of any kind of course. That was Sputnik in 1957. The Soviets went on to launch the first animals in space, the first probe to the Moon, the first human being in space Yuri Gagarin. They launched the first female astronaut, the first spaceship with two people in it, and they did the first spacewalk with a cosmonaut leaving a spaceship.

In the spring of 1961, President Kennedy had become frustrated with what he called "one Soviet space spectacular after another." As he told his senior aides, "Coming in second in space is the same as losing." Kennedy didn't think the United States should be losing. People and nations around the world didn't just think the Russians were challenging the U.S. in engineering and space technology; people thought the Soviets were better than the U.S.

Kennedy asked for a plan not just to get ahead but to leapfrog the Soviets. His advisors agreed. The way to take the lead vividly and boldly was to take America to the Moon. Privately, before Kennedy announced the goal, NASA told him that the odds of making it to the Moon and back safely by the end of the decade were just 50/50. It was a bold plan but also a risky plan.

Kennedy knew that simply announcing the mission, rallying Americans to that cause, would change the odds dramatically in favor of success. When President Kennedy said let's go to the Moon in May 1961, it was impossible. There was no rocket big enough to fly to the Moon, no spaceship that could land there, no computer small enough and powerful enough anywhere in the world that could fly a spaceship to the Moon.

In just 8 years, NASA and the people working with NASA solved 10,000 problems. They invented space travel. They pushed the technological limits of everything from rocket engines and spacesuit design to computing and the management of a vast battalion of 410,000 people working toward a single goal. That's what it took to get to the Moon, the work not just of the astronauts, which is so well-known, but the work of 410,000 people back on Earth for just 11 missions, more people working to get those astronauts to the Moon than were fighting in Vietnam for 3 years of the war. Going to the Moon was the biggest project outside of war human beings have ever undertaken.

The results were more than spectacular. Every Moon mission was a success. Even Apollo 13, which was a near disaster, was turned into a success by the determination and ingenuity of the staff in mission control and the astronauts on the crippled spaceship. Apollo was in fact a government program that came in on time, on budget, scandal-free, and was a stunning, worldwide achievement.

But here's the most important thing. Apollo was not a one-off performance, a brilliant show to end the 1960s. Apollo's legacy is incredibly important, and we mostly get the legacy wrong. It has nothing to do with Tang and Velcro. The legacy is much richer and much larger than Apollo gets credit for.

Apollo didn't end up launching the Space Age as it was imagined. It did something much more important right here on Earth. The spaceship computers that flew Apollo to the Moon were the smallest, fastest, most nimble computers ever created at that time. They not only did the job, they did it perfectly. Their development for the race to the Moon dramatically accelerated the digital revolution both deep inside the computer industry and across American society. The race to the Moon helped create the world we all live in today. Apollo changed the world by laying the foundation not for the Space Age but for the Digital Age.

We got a lot more than digital technology from Apollo, of course. It transformed our scientific understanding of the formation of both the Earth and the Moon. It inspired a generation of young people to become scientists and engineers and computer programmers. And yes, it taught us to fly in space.

The 50th anniversary of Apollo's first landing on the Moon should not be swaddled in nostalgia. It should be a moment to step back and reassess what we actually got from the Moon and appreciate it. Thank you.

[The prepared statement of Mr. Fishman follows:]

House Committee Testimony
Oral Statement
16 July 2019
Charles N. Fishman
Author, "One Giant Leap," the story of the race to the Moon
(919) 696-6980
cnfish@mindspring.com

"The Legacy of Apollo: What We Get Wrong"

Ladies and gentlemen of the Committee, thank you so much for the chance to speak today, on the anniversary of the launch of the first Apollo mission to land on the Moon.

I want to take you back briefly to the late 1950s and early 1960s. That was a time when the Soviet Union was absolutely crushing the United States when it came to achievements in space.

The Soviets launched the first spacecraft of any kind — that was Sputnik in 1957.

Then the Soviets launched the first animals to space, the first probe to the Moon, the first human being into space — that was Yuri Gagarin.

They would go on to launch the first female astronaut, and the first spaceship with two people in it, and do the first spacewalk, with a cosmonaut leaving the spaceship.

In the spring of 1961, President Kennedy had become frustrated with seeing one Soviet "space spectacular," as he called them, after another. As he told his senior aides, "Coming in second in space is the same as losing." Kennedy didn't think the United States should be losing.

The Soviet space spectaculars were having a significant impact in shaping world opinion during the Cold War. People and nations around the world didn't just think the Russians were challenging the U.S. in engineering and technology, people thought the Soviets were better than the U.S.

Kennedy asked for a plan not just to get ahead, but to "leap frog" the Soviets.

His advisors agreed: The way to re-take the lead, vividly and boldly, was to take America to the Moon.

Privately, before Kennedy announced the goal, NASA told him the odds of making it to the Moon and back, safely, by the end of the decade were just 50/50. It was a bold plan, but also a risky one.

Kennedy knew that simply announcing the mission, rallying Americans to that cause, would change those odds dramatically in favor of success.

• • •

When Kennedy said, Let's go to the Moon in May 1961, it was impossible.

There was no rocket big enough to fly to the Moon, no spaceship that could land there, no computer small enough and powerful enough — anywhere in the world — that could fly a spaceship to the Moon.

In just eight years, NASA and the people working with NASA solved 10,000 problems — they invented space travel, they pushed the technological limits of everything from rocket engines and spacesuit design, to computing power and the management of a vast battalion of 410,000 people, working toward a single goal.

Because that's what it took to go to the Moon — the work not just of the astronauts, which is so well known and so well told. But the work of 410,000 people back on Earth, for just 11 missions — more people working to get those astronauts to the Moon than were fighting in Vietnam three years of the war.

Going to the Moon was the biggest project, outside of war, human beings have ever undertaken.

• • •

But the results were more than spectacular.

Every Moon mission was a success. Even Apollo 13, which was a near disaster, was turned into a success by the determination and ingenuity of the staff on the ground, and the astronauts in that crippled spaceship.

Apollo was, in fact, a government program that came in on time, on budget, scandal-free — and was a stunning, worldwide achievement.

But here's the most important thing: Apollo was not a one-off performance, a brilliant show to end the 1960s.

Apollo's legacy is incredibly important, and we mostly get the legacy wrong. It has nothing to do with Tang and Velcro.

The legacy is much richer and much larger than Apollo gets credit for. Apollo didn't end up launching the Space Age as it was imagined then. Apollo did something much more important, right here on Earth.

The spaceship computers that flew Apollo to the Moon were the smallest, fastest, most nimble computers ever created at that time —

they not only did the job, they did it perfectly. Their development for the race to the Moon dramatically accelerated the digital revolution — both deep inside the computer industry, and across American society. It helped create the world we all live in today.

Apollo laid the foundation, not for the Space Age, but for the Digital Age.

We got a lot more than digital technology from Apollo — it transformed our scientific understanding of the formation of both the Earth and the Moon. It inspired a generation of young people to become scientists and engineers and computer programmers.

And yes: It also taught us how to fly in space.

The 50th anniversary of Apollo 11's first landing on the Moon should not be swaddled in nostalgia. It should be a moment to step back and reassess what we actually got from going to the Moon — and to appreciate it.

The idea that going to the Moon was an expensive Cold War stunt is mythology. It's unworthy of the achievement, of the people who made it happen, and of the problems they solved.

Americans literally did something in eight years that had been impossible — they worked together, during a hugely divisive era, to make the impossible possible. That is the spirit of America, and also the best of the America. We love to rise to the occasion.

Perhaps the most important legacy of Apollo is to be reminded that Americans will solve the hardest problems that are put to them. They just have to be asked.

# # #

House Committee Testimony
Biography
16 July 2019

Charles N. Fishman
Author, "One Giant Leap," the story of the race to the Moon
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cnfish@mindspring.com

Charles Fishman, journalist and author

Charles Fishman is a journalist and the author of *One Giant Leap: The Impossible Mission that Flew Us To the Moon*, his rollicking re-telling of the race to the Moon in the 1960s, and how it shapes the way we live now. The book became a *New York Times* bestseller in its first week.

Fishman is an award-winning reporter, magazine writer and author, who started his career at the *Washington Post*, where he spent seven months covering the space shuttle *Challenger* disaster in 1986. He has been reporting on space ever since, for *The Atlantic*, *Smithsonian,* and for *Fast Company* magazine, his long-time professional home.

His book on Wal-Mart, and its impact on the economy of the United States — *The Wal-Mart Effect* — was also a *New York Times* bestseller, and it was the first book to pierce Wal-Mart's veil of secrecy. *The Wal-Mart Effect* changed how people thought about Wal-Mart, and is still the standard text for understanding the largest company in the world, used in business schools and universities around the country.

Fishman's book *The Big Thirst* is the nation's bestselling book about water and our relationship to it. *The Big Thirst* reshaped the conversation about water and how to manage it more smartly in an era of scarcity in communities not just in the U.S., but around the world.

As part of the reporting for *One Giant Leap*, Fishman flew in zero-gravity. More than just a re-telling of the story of Apollo, *One Giant Leap* aims to reframe the conversation about the race to the Moon, so that the historical impact Apollo had is more clearly understood.

Charles Fishman is a graduate of Harvard College. He lives with his wife, also a journalist, their two children, and two labradors, in Washington, DC.

# # #

Chairwoman JOHNSON. Thank you very much. Dr. Miller.

TESTIMONY OF DR. DAVID W. MILLER, VICE PRESIDENT AND CHIEF TECHNOLOGY OFFICER, THE AEROSPACE CORPORATION

Dr. MILLER. Thank you for the opportunity to speak with you today about the technological legacy of Apollo. Many of the capabilities that we take for granted today had their roots in the investments that were made in the 1950s and 1960s to put humans on the Moon. For example, high-thrust yet fuel-efficient rocket engines made it possible to place large satellites in orbit.

This in turn enabled worldwide data and voice communication networks, brought us GPS navigation, television broadcasting, Earth monitoring for land management such as agriculture, and weather monitoring to enable accurate forecasts. Capabilities such as wireless hand-held power tools; lightweight thermal insulation; foam materials to cushion against vibration and shock; advanced, lightweight, and high-temperature materials; inertial guidance and navigation; integrated circuits and microchips—you're going to hear these repeated today—and many nutritional additives either found their start in or their development was greatly accelerated by Apollo.

While the list goes on, I'd also like to focus for a moment on the computers which, in 2019, permeate our everyday lives. Before Apollo, computers were used to perform mathematical calculations. They filled large rooms. This required us to go to the computers to use them. Apollo changed all that. Apollo was the first time that humans demonstrated that computers could come with us in our cars, in our homes, in our trains, and our planes, even on our laps and in our pockets. By Apollo demonstrating that digital computers could assist us on humanity's furthest journey, we realized that computers could assist us on any journey.

But this did not come easy. The Apollo scientists and engineers needed to miniaturize these computers, which until then had only fit in rooms, to the size of 1 cubic foot. They coined the phrase software engineering. They invented the real-time operating system. Unlike the operating system in your laptop which slows down as you ask it to do more, a real-time operating system maintains its speed by delaying lower-priority tasks.

You may remember the 1202 alarm during the descent of Apollo 11's lunar module to the surface of the Moon. That was not a sign of a problem. Instead, it was a sign that this new and innovative operating system could reliably continue to execute a critical task even when it was asked to do more than it could handle. That's why the basic principles of real-time operating systems are still at the core of all the digital controllers in almost anything we use today, autopilots, cruise control, environmental control systems, power grids, medical devices, phones, internet, just about everything that defines our technological world.

Apollo spacesuits were the first smart clothes with wearable technologies, first to have wired—wireless headsets, embedded medical sensors, and portable life-support systems that now benefit firefighters and other hazardous fields—career fields. Flight simulators for commercial and military aviation are safe and cost-effective tools for pilot training that came out of the Apollo simulator program. Apollo married digital computers with engineering design methods to spearhead the field of CAD, computer-aided design, which is essential in designing almost every complex system that we design today.

But perhaps the most important technological legacy of Apollo is the inspiration it gave to several generations of scientists, engineers to pursue STEM education and careers. In turn, these generations have developed entirely new industries, made groundbreaking discoveries, and inspired and educated subsequent generations not only in the field of space but many others.

As an educator, I have firsthand experience in the power of inspiration. When it comes to space, the United States is the greenest pasture, and many of the brightest from around the world seek an education and follow-on career right here.

To borrow a quote from Plutarch, "The mind is not a vessel to be filled but a fire to be kindled." Apollo kindled the passion to take big strides to not back away from a daunting challenge but to instead embrace and tackle that challenge. This does not apply solely to space. It applies to all domains of intellectual effort. If we can put a human on the Moon, we can surely do anything we set our minds to.

So while it's important to take pause and look back at the technological achievements gained through the original Apollo program, it's also important to consider the exciting next steps of lunar exploration and development will be even more challenging than Apollo. The scale of technological advancement is directly proportional to the length of the stride we choose to make.

The next generation of lunar missions will require larger habitats with closed-loop life support systems, long-term radiation protection, telemedicine, autonomous operations and repair, the ability to independently generation—generate consumables such as food and water—basically live off the land—and do all this at a level of reliability, adaptability, and efficiency that will revolutionize what and how we do things right here on Earth.

These requirements for operations on the Moon and beyond will drive a search for creative technical solutions and their inevitable terrestrial applications, surpassing those that we've seen in the Space Age thus far. Just as Apollo brought about substantial technical advancements, we should be excited about the future technology that would merge as a result of continued space exploration. In the words—because, in the words of President Kennedy, that goal will serve to organize and measure the best of our energies and skills.

Thank you, and I look forward to your questions.

[The prepared statement of Dr. Miller follows:]

Testimony of

Dr. David W. Miller
Vice President and Chief Technology Officer
The Aerospace Corporation

For the hearing entitled

The Apollo Legacy

Before the

Committee on Science, Space and Technology
United State House of Representatives
Room 2318, Rayburn House Office Building
10:00 a.m., July 16, 2019

Thank you for the opportunity to speak with you today about the technological legacy of Apollo. Many of the capabilities that we take for granted today had their roots in the technological investments made in the 1950s and 60s to put humans on the Moon. For example, high thrust yet fuel efficient rocket engines made it possible to place large satellites in orbit for worldwide data and voice communication networks, GPS navigation, television broadcasting, Earth monitoring for agriculture, and weather monitoring to enable accurate forecasts. Wireless handheld power tools, lightweight thermal insulation, foam materials to cushion against vibration and shock, advanced lightweight and high temperature materials, inertial guidance and navigation, integrated circuits and microchips, compact medical sensors, and many nutritional additives either found their start in, or their development was greatly accelerated by, Apollo. While the list goes on, I'd like to focus for a moment on computers which, in 2019, permeate our everyday lives.

Before Apollo, computers were used to perform large mathematical calculations. They filled large rooms in buildings. This required us to go to the computers in order to use them. Apollo changed all that. Apollo was the first time humans demonstrated that computers could come with us: in our cars, in our homes, in our trains, in our planes, even on our laps and in our pockets. By Apollo demonstrating that digital computers could assist us on humanity's furthest journey, we realized that computers could assist us on any journey. But this did not come easy. The Apollo scientists and engineers needed to miniaturize computers, that until then had only fit in rooms, to the size of one cubic foot. They coined the phrase "software engineering." They invented the real-time operating system. Unlike the operating system in your laptop, which slows down as you ask it to do more, a real-time operating system maintains its speed by delaying lower priority tasks. The 1202 alarm during the descent of Apollo 11's Lunar Module was not a sign of a problem. Instead, it was a sign that this new and innovative operating system could reliably continue to execute a critical task even when it was asked to do more than it could handle. This is why the basic principles of real-time operating systems are still at the core of the digital controllers in almost everything we use today: autopilots, cruise control, trains, environmental control systems, power grids, communications networks, phones, internet, just about everything that defines our technological world.

Apollo spacesuits were the first smart clothes with wearable technologies. They had wireless headsets, embedded medical sensors, and portable life support systems that now support firefighters and other hazardous career fields. Flight simulators for commercial and military aviation are safe and cost-effective tools for pilot training that came out of the Apollo simulator program. Apollo married digital computers with engineering design methods to spearhead the field of CAD, or computer aided design, which today spans all engineering disciplines and is essential in designing today's complex systems.

But perhaps the most important technological legacy of Apollo is the inspiration it gave to several generations of scientists and engineers to pursue STEM education and careers. In turn, these generations have developed entirely new industries, made ground-breaking discoveries, and inspired and educated the subsequent generations not only in the field of space but many others. As an educator, I have first hand experience in the power of inspiration. When it comes to space, the United States is the greenest pasture and many of the brightest from around the world seek an education and follow-on career here. To borrow a quote from Plutarch, "The mind is not a vessel to be filled, but a fire to be kindled." Apollo kindled the passion to take big strides, to not back away from a daunting challenge but to instead embrace and tackle that challenge.

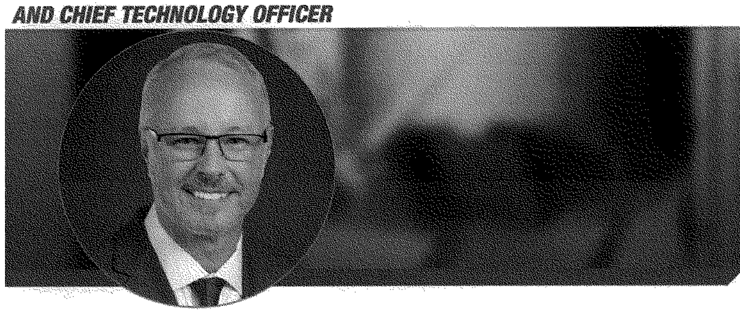
This does not apply solely to space, it applies to all domains of intellectual effort. If we can put a human on the Moon, we can surely do anything we set our minds to.

While it is important to take pause and look back at all of the technological achievements gained through the original Apollo program, it is also important to consider the exciting next steps in lunar exploration and development which will be even more challenging than Apollo. The scale of technological advancement is directly correlated with the length of the stride we choose to make. The next generation of lunar missions will require larger habitats with closed-loop life support systems, long-term radiation protection, tele-medicine, autonomous operations and repair, the ability to independently generate consumables such as food and energy, the establishment of a routine logistics supply operation covering a distance of a quarter-million miles and do all this at a level of reliability, adaptability, and efficiency that will revolutionize what and how we do things right here on Earth. These requirements for operations on the Moon – and beyond – will drive a search for creative technical solutions, and their inevitable terrestrial applications, surpassing those that we've seen in the space age thus far. Just as Apollo brought about substantial technical advancements, we should be excited about the future technology that will emerge as a result of continued space exploration because, in the words of President Kennedy, that goal will serve to organize and measure the best of our energies and skills.

Thank you and I look forward to your questions.

AEROSPACE

DAVID W. MILLER
VICE PRESIDENT AND CHIEF TECHNOLOGY OFFICER



Dr. David W. (Dave) Miller is vice president and chief technology officer (CTO) at The Aerospace Corporation. He joined the company in January 2019. In this newly created role, Miller is responsible for providing vital leadership for the company's growing prototyping efforts through his supervision of Aerospace's Experiments Lab (the newly named "xLab"), previously called the Technology Demonstration Center. He will also oversee iLab (Aerospace's innovation laboratory, where staff collaborate in a creative space to develop ideas into game-changing technologies); the Engineering, Science & Technology Hubs; and the Tech Fellows program.

Prior to joining Aerospace, Miller was director of the Space Systems Laboratory and the Jerome C. Hunsaker Professor in the Department of Aeronautics and Astronautics at the Massachusetts Institute of Technology. Earlier in his career, he served five years—two as vice chair—on the Air Force Scientific Advisory Board, which is a Federal Advisory Committee that provides independent counsel on science and technology matters relating to the Air Force's mission. He also served as NASA's chief technologist at its headquarters in Washington, DC.

Miller has helped develop an extensive set of dynamics and controls technology laboratories on the space shuttle, the Mir space station, and the International Space Station. He is currently developing reconfigurable spacecraft concepts that permit a variety of capabilities through proximity operations and docking of modular satellites. Miller has also helped develop a technique to control satellite formations without the need for propellant.

Miller's comprehensive research experience, vast technical knowledge, investigative skills, and unique teaching abilities have prepared him to lead in the creation of agile space solutions for the most critical issues challenging Aerospace's customers.

Education
Miller earned his bachelor's and master's degrees and a Ph.D. in aeronautics and astronautics, all from the Massachusetts Institute of Technology.

Affiliations
Miller is a Fellow of the American Institute of Aeronautics and Astronautics.

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Chairwoman JOHNSON. Thank you very much. Dr. Jakab.

TESTIMONY OF DR. PETER L. JAKAB, CHIEF CURATOR, SMITHSONIAN NATIONAL AIR AND SPACE MUSEUM

Dr. JAKAB. Chairwoman Johnson, Ranking Member Lucas, and the Members of the Committee, thank you for this opportunity to take a look back and consider the lessons of Apollo.

As we reflect on the Apollo era and the extraordinary achievement of the lunar landings a half-century ago, it's very easy and quite appropriate to see them through the lens of awe, excitement, amazement, pride, inspiration, and perhaps humanity's greatest moment of unity. For those of us who can remember the bulky space-suited figures bounce-stepping on the lunar surface first-hand—and I'm among them—retelling the story still never fails to bring us right back to those exciting moments.

For those who only know it know it through the stories, Apollo stands as a historical lesson and a powerful cultural milestone for what we can achieve looking forward. Simply stated, Apollo allows us to focus on who we are as a Nation and what humanity can achieve. But those first steps on the Moon are also a window onto the complexity of history and how historical events have many threads and interconnections.

I'd like to share two examples about—one about technology and one about politics and diplomacy. It's often suggested that all sorts of new technologies emerged from Apollo and the Space Age in general, and in some ways that's true. We've here heard a few examples just a moment ago. In broad strokes, we can talk about how the space-based technologies have shaped our current lives. One need look no further than the satellites orbiting our planet to connect us and provide information we rely on every day. But this reality I believe does tend to give an impression that everything about Apollo technology was cutting-edge and completely innovative.

An interesting aspect of getting to the Moon was how much off-the-shelf technology was used and adapted. This was driven by one very powerful requirement: If you have people in a spacecraft traveling hundreds of thousands of miles away from Earth, everything has to work. There's little margin for troubleshooting a new technology on your way to the Moon. The safety of the astronauts was forefront—was in the forefront of everyone's thinking. Engineers working on Apollo tried to take advantage of proven technologies as much as possible to achieve the best chance of reliability.

This context gives special significance to one technological choice that was critical to Apollo's success, and that was the decision to use the then-new technology of the integrated circuit for the vital Apollo guidance computer. Using integrated circuit—or the chip as we often call it today—will seem in retrospect an obvious choice. Size and weight is everything in spacecraft design, and these tiny wonders would seem a perfect application for this task. But in the early 1960s integrated circuits were largely untested and their reliability unknown. Using integrated circuits in the vital guidance system was a bold decision and illustrates that the path to success, especially a success as momentous as landing on the Moon, is never straightforward.

In the end, the decision to go with the integrated circuit proved to be the right one. None of the Apollo missions ever experienced a hardware failure in the guidance computer. But the story doesn't end there. Spurred in part by the use of the integrated circuits in the initial Apollo spacecraft design, the industry took off and engineers quickly were cramming more and more components onto integrated circuits. Remarkably, the advancing technology moved so quickly there was no way to adequately test it for the computers on the later Apollo missions because of the concern for reliability that I just mentioned.

But the breadth of other applications quickly spread, and by the 1960s—by the end of the 1960s an industry was in full spring, particularly in an area of California that soon came to be known as Silicon Valley.

The Apollo program was not the sole reason for the transformation of Silicon Valley, but it was a major factor. As we enjoy the many electronic devices that enhance our lives today, we should recall the courage of the Apollo engineers who were audacious enough to choose a circuit made of a sliver of silicon to guide our astronauts to a safe landing on the Moon.

Let me now turn to a very different part of the Apollo story. With a safe return of the Apollo 11 astronauts, the world embraced the achievement not just as an American accomplishment but one the entire world could take pride in. In the persons of Neil Armstrong and Buzz Aldrin, with Michael Collins orbiting close by, humans stepped on another world for the first time. Symbolically, as Armstrong so famously proclaimed, it was a giant leap for us all.

President Kennedy's bold commitment to land humans on the surface of the Moon by the end of the decade had been fulfilled, and across the globe people felt a part of it. Yet as stunning a technological achievement as Apollo was, it is also important to understand the political dimension of the program as well. Made at the height of the Cold War, Kennedy's call to action had a significant political context. Landing on the Moon and doing so first was as much about making the political statement as it was about science and technology.

After Apollo 11—after the Apollo 11 crew returned safely to the Earth, President Nixon instinctively grasped the value of Apollo beyond the science and quickly sought to leverage the diplomatic opportunities presented by the success of Apollo 11. After greeting and congratulating the astronauts on board the USS Hornet, Nixon began a 12-day 8-nation diplomatic tour of Asia and Europe called Moonglow to promote the spirit of Apollo and foster goodwill and international cooperation. This was followed shortly thereafter by a goodwill tour by the astronauts themselves visiting 30 cities around the world in 2 months.

The launch of Apollo was rooted in competition. The success of Apollo provided an impetus to focus on cooperation. Among other diplomatic overtures, the afterglow of Apollo was a factor in Nixon's efforts to open China and advance detente with the Soviet Union. However short-lived those successes may have been and limited in long-term effect, this foray into space diplomacy was not without consequence. That brief period of unity surrounding the success of Apollo had impact on Earth in ways unanticipated when the Saturn V rocket launched Apollo 11 toward the Moon 50 years ago today. This is another example of how history illustrates the many complex threads of human endeavor.

As we celebrate the thrill and inspiration of Apollo on this anniversary, let us also recognize the value of history to understand and illuminate the many layers of the past. Thank you, and I'll be happy to address any comments or questions you may have.

[The prepared statement of Dr. Jakab follows:]

Written Statement of Dr. Peter L. Jakab
Chief Curator, Smithsonian National Air and Space Museum
before the
Committee on Science, Space, and Technology
United States House of Representatives

Chairwoman Johnson, Ranking Member Lucas, and Members of the Committee, thank you for the opportunity share reflections and lessons of Apollo.

As we reflect on the Apollo era and the extraordinary achievement of the lunar landings a half century ago, it is very easy, and quite appropriate, to see them through the lens of awe, amazement, pride, inspiration, and perhaps humanity's greatest moment of unity. For those of us who can remember the bulky-spacesuited figures bounce-stepping on the lunar surface first hand, retelling the story still never fails to bring us right back to those exciting moments. For those who only know of it through those stories, Apollo stands as a historical lesson and powerful cultural milestone for what we can achieve looking forward. Simply stated, Apollo allows us to focus on who we are as a nation and what humanity can achieve. But those first steps on the Moon also are a window onto to the complexity of history and how historical events have many threads and interconnections. I'd like to share two brief examples, one about technology, and one about politics and diplomacy.

It is often suggested that all sorts of new technologies emerged from Apollo and the space age in general, and in some ways that is true. In broad strokes we can talk about how space based technologies have shaped our current lives. One need look no further than the satellites orbiting our planet that connect us and provide information we rely on every day. But this reality, I believe, does tend to give the impression that everything about Apollo technology was cutting edge and completely innovative. An interesting aspect of getting to the Moon was how much off-the-shelf technology was used and adapted. This was driven by one very powerful requirement: If you have people in a spacecraft traveling hundreds of thousand miles away from Earth, everything *has* to work. There was little margin for trouble shooting new technology on your way to the Moon. The safety of the astronauts was at the forefront of everyone's thinking. Engineers working on Apollo tried to take advantage of proven technologies as much as possible to achieve the best chance of reliability. This context gives special significance to one technological choice that was critical to Apollo's success. That was the decision to use the then new integrated circuit technology for the vital Apollo guidance computer.

Using the integrated circuit, or "chip" as we often call it today, would seem in retrospect an obvious choice. Size and weight was everything in spacecraft design, and these tiny wonders would seem perfect for this application. But in the early 1960s, integrated circuits were largely untested and their reliability unknown. Using integrated circuits in the vital guidance system was a bold decision, and illustrates that the path to success, especially a success as momentous as landing on the Moon, is never straight forward. In the end, the decision to go with the integrated circuit proved to be the right one. None of the Apollo missions ever experienced a hardware failure in the guidance computer.

But the story doesn't end there. Spurred, in part, by the use of integrated circuits in the initial Apollo spacecraft design, the industry took off and engineers quickly were cramming more and more components onto integrated circuits. Remarkably, the advancing technology moved so quickly there was no way to adequately test it for the computers on the later Apollo missions because of the concern for reliability I talked about earlier. But the breadth of other applications quickly spread and by the end of the 1960s an industry was in full swing, particularly in an area of California that soon came to be known as "Silicon Valley." The Apollo program was not the sole reason for the transformation of Silicon Valley, but it was a major factor. As we enjoy the many electronic devices that enhance our lives today, we should recall the courage of Apollo engineers who were bold enough to choose a circuit made of a sliver of silicon to guide our astronauts to a safe landing on the Moon.

Let me now turn to a very different part of the Apollo story. With the safe return of the Apollo 11 astronauts the world embraced the achievement not just as an American accomplishment, but one the entire world could take pride in. In the persons of Armstrong and Aldrin, with Collins orbiting close by, humans stepped on another world for the first time. Symbolically, as Armstrong so famously proclaimed, it was a "giant leap" for us all. President Kennedy's famous commitment to land humans on the surface of the Moon by the end of the decade had been fulfilled, and across the globe people felt a part of it. Yet, as stunning a technical achievement as Apollo was, it is also important to understand the political dimension of the program as well. Made at the height of the Cold War, Kennedy's call to action had a significant political context.

Landing on the Moon, and doing so first, was as much about making a political statement as it was about science and engineering.

After the Apollo 11 crew returned safely to Earth, President Nixon instinctively grasped the value of Apollo beyond the science, and quickly sought to leverage the diplomatic opportunities presented by the success of Apollo 11. After greeting and congratulating the astronauts on board the USS *Hornet*, Nixon began a 12-day, eight-nation diplomatic tour of Asia and Europe, called "Moonglow," to promote the "spirit of Apollo" and foster goodwill and international cooperation. This was followed shortly thereafter by a goodwill tour by the astronauts themselves, visiting 30 cities around the world in two months. The launch of Apollo was rooted in competition. The success of Apollo provided an impetus to focus on cooperation. Among other diplomatic overtures, the afterglow of Apollo was a factor in Nixon's efforts to open China and advance détente with the Soviet Union. This foray into "space diplomacy" was not without consequence. That period of unity surrounding the success of Apollo had impact on Earth in ways unanticipated when the Saturn V rocket launched Apollo 11 toward the Moon 50 years ago today. This is another example of how history illustrates the many complex threads of human endeavor. As we celebrate the thrill and inspiration of Apollo on this anniversary, let us also recognize the value of history to understand and illuminate the many layers of the past.

Peter L. Jakab, Ph.D.
Chief Curator
Smithsonian National Air and Space Museum

Dr. Peter L. Jakab is Chief Curator of the Smithsonian National Air and Space Museum, (NASM). Formerly he served as the museum's Associate Director for Collections and Curatorial Affairs. He has been with NASM since 1983. He holds a BA, MA, and Ph.D. in American history from Rutgers University. Areas of specialization include the history of technology, aerospace history, and American social and cultural history. Prior museum work includes stays at the Edison National Historic Site, West Orange, N.J., and the New Jersey Historical Commission. He also spent a year with the Thomas A. Edison Papers Project and two years teaching American history at Rutgers University during his graduate study. During his stay at the NASM, he has curated numerous exhibitions and frequently lectured on the history of technology, the history of invention, the Wright brothers and pioneer aviation, and First World War aviation. His most recent exhibition is *Artist Soldiers: Artistic Expression in the First World War,* at the National Air and Space Museum. Major exhibitions also at the National Air and Space Museum include *Leonardo da Vinci's Codex on the Flight of Birds,* featuring the original da Vinci Codex, and *The Wright Brothers & the Invention of the Aerial Age.* His publications include the books *Visions of a Flying Machine: The Wright Brothers and the Process of Invention* (Smithsonian Institution Press, 1990); *Icare: revue de l'aviation française, #147, Les Frères Wright*, 1994; *The Published Writings of Wilbur and Orville Wright* (Smithsonian Institution Press, 2000), and *The Wright Brothers and the Invention of the Aerial Age* (National Geographic Society, 2003), the companion book to the exhibition.

Chairwoman JOHNSON. Thank you very much. At this point we'll begin our first round of questions. And I'll recognize myself for 5 minutes.

Mr. Fishman, can you set the stage for us? What was the environment in the late 1950s through the 1960s? What were the driving factors internationally and domestically leading to President Kennedy's proposing to go to the Moon, and how did he convince Members of Congress to go along with it despite a majority of Americans thinking it wasn't worth the cost until a brief moment after Apollo 11, according to the former NASA Chief Historian?

Mr. FISHMAN. Sure. The context was set really by Sputnik and then by Yuri Gagarin. The Russians really did a whole series of space performances that got the world's attention. Sputnik of course was just a beach ball-sized satellite launched in 1957. Thirty days later, the Russians launched Sputnik 2, which contained the dog Laika and weighed 1,200 pounds. So 30 days into the Space Age, they had a spaceship that had a capsule, a live creature in it, life-support systems, and a little TV camera beaming back pictures of the dog. Our plan at that moment was to launch a 25-pound satellite, and that didn't come for months.

When John Kennedy became President, just a few months in they launched the first human being into space, Yuri Gagarin, and that had the same kind of galvanic effect across the world as Sputnik had. In fact, there were congressional hearings the day after Yuri Gagarin's flight. The head of NASA Jim Webb was called before Congress, and a—it was a bipartisan effort, and there was a lot of frustration. A Republican Congressman from Pennsylvania said to Jim Webb, Mr. Webb, tell us how much money you need. We will give it to you, words rarely heard in Congress.

So when, 6 weeks later, President Kennedy gave what was—what the White House called a second State of the Union Address, and as part of that, asked Americans to support going to the Moon, there was wide support very quickly.

Just one point of reference, when Kennedy said in May 1961, let's go to the Moon, more than half of Americans had never been on an airplane yet, so he was asking Americans to fly to the Moon, and most Americans had never been off the ground themselves. So it was really a leap of leadership but also of frustration.

Mr. LUCAS. Madam Chair, could we ask our friends to pull those microphones directly in front of us since the good part of this is being able for us to hear you but also the historic record of what we're discussing here today, so line them up, guys.

Chairwoman JOHNSON. Thank you. Dr. Miller, give us a little perspective of how you felt back during that time or where you were.

Dr. MILLER. Well, this is a little bit of a personal story, but I remember my mom would keep me home from school to watch the Gemini missions and the Apollo missions, and I remember the school would call and say your son's not getting an education, and my mom would read them the Riot Act.

So I remember being 9 watching them land on the Moon and, you know, I think I was—well, I was old enough to know it wasn't magic, but I was young enough to not see any limits. And I found that very powerful.

Chairwoman JOHNSON. Dr. Jakab?

Dr. JAKAB. [Audio malfunction.] With just the shirts on their back and a 2-year-old son arrived here in the United States and were able to start a new life here. I was born shortly thereafter. So for them, the United States' achievement of landing a man on the Moon had a very significant and powerful political context from which the Soviet-dominated society that they fled. So for them it was very much a—yes, we did beat the Russians, and they were very pleased about that. So I remember as a young boy what the Apollo accomplishment meant to people who the United States was their adopted country and the place where they sought freedom. And so Apollo had many dimensions, not just simply the tremendous technological achievement, but it had great powerful meaning for many, many people in many ways.

Chairwoman JOHNSON. Yes. Thank you very much. My time is expired. Mr. Lucas.

Mr. LUCAS. Thank you, Madam Chair.

And, Dr. Miller, obviously you and I are the same age. I was 9 years old that summer, and July 1969 will ever be imprinted in my mind not just because of Apollo but because I had an appendectomy two weeks before the landing, so that's a really memorable month in my lifetime.

Three of my four grandparents were born before Kitty Hawk, so as a kid, I can remember the discussion amongst the elders about was this real, was this cost-effective, but this was a generation literally that had been born before modern air flight.

That said—and I address my questions to all of you, and whoever wants to speak can, but just from a perspective in your opinion each, what was the most significant impact of the Apollo missions? If you can grind it down, either, any, or.

Dr. MILLER. I think I captured in my statement and I would go back to, you know, it's that if we can have a mission that we believe in and we put the appropriate resources to it, and I think if we can show our trust and respect for the younger generation, which Apollo was, they could achieve extraordinary things. And I think we're seeing that today. You know, I think we're seeing that in these emerging commercial sector for launching satellites. They're hiring up my students like crazy. That's—it's no longer their grandparents' space program, it's their space program, and they're just catching fire. And I—we're seeing it again, and I hope it stays.

Mr. FISHMAN. I think it's important to appreciate that it was literally impossible when Kennedy said do it, and Americans love to be told something's impossible and then prove that it's possible. And the people—Apollo is often cast as a kind of heroic story, and in some ways it is, but there were no superheroes. There were just ordinary Americans. And in the last 4 years I've had the wonderful chance to talk to literally hundreds of people who worked on Apollo, and they will tell you that the mission got out of them a quality of work, a caliber of work that they would not have been capable of otherwise. So ordinary Americans like to be asked to do something that seems almost unachievable and then prove that it is achievable in service of a larger mission. And I think we have lost track of that a little bit, but we like to work together, and we like to rise to the occasion.

Dr. JAKAB. Speaking from the museum perspective, we're fortunate at the Smithsonian to be the custodian for the American people of the Apollo 11 spacecraft, the actual artifact that accomplished this mission that we've been talking about. And our museum, the Air and Space Museum is filled with many amazing objects. But I often say that the museum is the place where the hardware and the humanity intersect because every object that we have, every artifact that we have, represents people. Somebody designed it, somebody flew it, somebody maintained it, somebody formed a company to promote it, somebody worked in an industry to support it. It's really all about people.

There's a famous story. It's probably apocryphal, but it's one of those good apocryphal stories that does make a meaningful point. During the Apollo era a custodial worker at NASA was asked, well, what are you doing? What are you doing here? And he said I'm helping us get to the Moon. And that—it still kind of chokes me up when I hear that because it really does say what is Apollo about. Apollo is about all of us finding what's the best in our self and applying it to a common goal. And if we can do that again, there's no limit to what we can achieve.

One of my favorite quotes from Mark Twain was he said, "History does not repeat itself, but it does rhyme." And I think by reflecting on the anniversary of Apollo, perhaps we can induce it to rhyme for us and bring us to another achievement that we can celebrate again in the future.

Mr. LUCAS. In the time I have left I'd like to focus for a moment not just on the pieces that brought all this together but thinking about where we go and how important those same pieces are in the future, and again anyone that would care to touch on this. But when I went through and looked at essentially the contractors who played a significant role in the Apollo program, huge number, North American Rockwell, now Boeing, built portions of the command and service module, as I proudly noted earlier, in my home State of Oklahoma. Boeing also built the Saturn V rocket. Lockheed Martin, now Northrup Grumman, built the launch escape system. Rocketdyne, now Aerojet Rocketdyne, built the F-1 and J-2 rocket engines. General Dynamics built the communications transponders. Pratt & Whitney, now UTC, built the fuel cells. Northrop Grumman built the lunar module. Raytheon built the guidance computer. Honeywell built the environmental control system. Avco, now Textron, built the heatshield. Harris, now L3 Harris, built the telemetry systems.

Looking back at how important that robust industrial base was to the success of Apollo, how important is a robust industrial base going to be for our future efforts because we don't have those kind of people to put the pieces together.

Dr. MILLER. So let me add to that that they also came under contract on the duration about—of weeks is how we—you know, they had to gear up. They had to gear up fast, and it all came together.

But I think, you know, there's been a lot of consolidation in the aerospace field, and, you know, a lot of that knowledge is still out there. But I think what we're seeing now is the emergence of the commercial sector. And—you know, and that ties in with, again, it's really—it's really the younger generation that's going into these startup companies that are no longer startups. They're real. Because I've seen over years launch companies come and go, and here's just yet another, but no, that's all changed now. And they've demonstrated that they deserve a role in making this happen, and so I think that's where we're going to see these new capabilities come along.

And I will add that it's essential that we—that as we do exploration, we have to bring the commercial sector along. Now, I'll use as an example Magellan. You know, he explored—circumnavigated the globe or almost made it, but he did not operate the port he left from. He did not build the ships, he did not grow the food on his ships. Some part of the economy was used to do that. Once he was outside the edge of that harbor, he was exploring. Apollo, that edge of the commercial harbor was on the ground at Cape Kennedy. Right now, that edge of the commercial harbor is in orbit around Earth. So as NASA moves out further, they've got to pull the commercial sector because they cannot support the entire logistics trail.

Mr. LUCAS. Mr. Fishman?

Mr. FISHMAN. I think one of the most exciting developments is SpaceX and Elon Musk and Blue Origin and Jeff Bezos, Robert Bigelow, Bigelow Aerospace. There is this whole wave of companies, private companies, that inspired in fact by that era, by Apollo, are doing things that we would never have imagined 20 years ago. And so there—the roster you read off is really impressive, and those companies still do impressive things. What's interesting is that in some ways the most dramatic innovation in rocketry is coming from SpaceX and Blue Origin. Those guys want to create what seems almost unimaginable now but a Southwest Airlines essentially of space travel.

Jeff Bezos talks about launching every Thursday. If you don't get on the Blue Origin rocket this Thursday, it's going again next Thursday. There are only between 90 and 100 launches a year worldwide now. If Jeff Bezos is launching to space 52 times a year in 5 years, that will be part of the transformation that sort of creates a space economy. And so there's going to be a role for R&D for the NASA side and a role for a space economy that is dynamic and innovative and also self-sustaining.

Mr. LUCAS. My time's expired. Thank you, Madam Chair, yield back.

Chairwoman JOHNSON. Thank you. Dr. Bera.

Mr. BERA. Thank you, Madam Chairwoman.

This is an exciting time. I'm excited about the anniversary. I can't say I remember the Apollo 11—I was 4 years old at the time-but growing up in Downey, California, home of Rockwell International at the heart of the Apollo mission, I remember the subsequent flights, remember the Land Rover—or the Moon rover I should say, you know, Skylab, Apollo-Soyuz, the Space Shuttle missions and the International Space Station, and it's remarkable. And, you know, we should take this opportunity, as we celebrate the 50th anniversary, to just remember what's possible, right?

As all three of you noted, when President Kennedy challenged us, we no idea how we were going to go to the Moon. We didn't have the technology. We had to dream the impossible and then go out there and make it happen. And that is an important reminder for us today and for our children and the next generation that, you know, American ingenuity, American innovation, American know-how and inspiration can do anything. And it wasn't just an accomplishment for the United States of America. This was an accomplishment for all of humankind.

And, you know, when we think about the challenges that we face, whether that's climate change, you know, food, water insecurity, we can solve all of these challenges if we put that issue out there. My colleague from Colorado is going to say we need to go to Mars by 2033. We can—he's got it right there. Look, if that's what we want to do, let's put it out there and let's challenge ourselves and let's then invest the resources, the ingenuity, inspire the next generation to make it happen.

The other thing that we had during Apollo and when President Kennedy challenged us was this wasn't a Democratic or a Republican issue. This was an American challenge and an American opportunity and the institution of Congress worked together in a sustained, focused way across, you know, different Congresses and Democratic and Republican Administrations. And we've got to remember that. You can't keep changing your mission every 4 years because it is very hard to make those investments.

We talked about, you know, some of the big companies that came off of this, but there's remarkable work already being done. You know, one company that I had a chance to go visit, Made In Space that is working out of Ames, they're looking at 3-D printing in space and using the International Space Station. What they're doing is they're thinking about, well, how do you take Moon dust and the raw materials that are out there and use that to create the building blocks for, you know, a permanent—and that's going to have huge applications here on Earth as well.

So, you know, maybe in the time I have remaining—you can tell I'm excited about this, but I'm excited about making sure our kids get that same inspiration that we all had when we were growing up and that we don't shy away from the impossible because it's easy to do what we know how to do. It's hard to do but necessary to do what we don't know how to do but that we want to do, and that's what we got to kind of get our mojo back as a country and a world and do this together.

Maybe the three of you quickly can answer what's the most important thing we can do to inspire that next generation to believe in the impossible, and what would you like to see us doing as Congress? Maybe we'll start with Dr. Jakab. You can go ahead and——

Dr. JAKAB. Well, the first thing I would suggest is bring your children to the National Air and Space Museum and——

Mr. BERA. I have.

Dr. JAKAB [continuing]. See the objects that were the products of the inspiration that we talked about in the 1960s and 1970s.

But I think, again, the—speaking from the museum point of view, the objects speak to us. The objects have power.

And one of the things that we try to do at the Air and Space Museum with these objects is not only to talk about the heroic stories of Armstrong, Aldrin, and Collins, but, again, the stories of the

400,000, all those who contributed. And I think one of the ways that you can inspire people, whether it's coming to the museum or seeing a film like "Hidden Figures" or something like that is for them to find themselves in the story. If you can see yourself or see someone that you can relate to in the story, then it becomes real. Then it becomes accessible. Then it becomes something, yes, I can do that. And then you can kind of latch onto the larger goal and be part of that. So I think a big part of how we inspire is having people find themselves in the story.

Mr. BERA. Dr. Miller?

Dr. MILLER. The—you know, when I was growing up, I was dying for some way to get involved with space but all I could do was watch the movies and read the books and all that. And what I— we're in a different age now with small satellites, the International Space Station. I'm going to borrow a phrase from a colleague who now works at Blue Origin. Kids can now touch space. They can actually get involved. There are robotics competitions that middle school kids are doing on Space Station right now. There are science programs where you can take a photo of your hometown off Space Station. There are these things that you can interact—have your kids interact with also, you know, terrestrial robotics competitions, you know, that cover different areas of STEM.

There's a lot of opportunity now if you look for them that your kids can get involved. And it's really supporting the pipeline starting in middle school.

Mr. BERA. Mr. Fishman.

Mr. FISHMAN. I would say that the most important thing is a sense of bipartisanship, clear goals, and the ability to move forward. Every President since Carter has laid out bold space goals, literally none of which have come to fruition in point of fact. And so that increases people's skepticism. OK, that was a spectacular speech and it would be lovely if we could do that, but then it doesn't happen.

One of the questions I get asked sometimes is, why did what— why did the speech Kennedy give actually result in us going to the Moon but the speech that, you know, George W. Bush gave did not in fact get us to Mars by 2025? And one of the answers is that the Kennedy Administration had done its advance work, and they knew that on Capitol Hill there would be support. And they weren't just stepping up to the plate and giving a speech. There were saying we're all going in the same direction together. And so I think bold goals are really valuable, but pulling people along and making the case widely about why those bold goals will serve us, I think that's also important.

Mr. BERA. Great. And we know "Mars 2033" fits on a bumper sticker, so maybe that's it. I'll yield back.

Chairwoman JOHNSON. Thank you very much. Mr. Posey.

Mr. POSEY. Thank you, Madam Chair. And thank you for holding this hearing today. And I thank our witnesses for attending. It's been a great walk down memory lane. It's great to see an unusually high number of young people in the audience today, what I would consider young anyway. And I can remember being not much younger than most of them sitting in class when the big news of the day was President Kennedy's speech at Rice University, why go to the Moon? Great countries do things, he said, not because they're easy but because they're hard. And it inspired me and so many others of my generation. He was an inspirational President for sure.

And I remember sitting at the desk in school and say, hey, you know, within 10 years, I want to put my fingerprints on the rocket that carries the first human beings to the Moon. And that was a prime goal for me as young man. And about five years later, you left off McDonnell Douglas, Mr. Ranking Member, as a big contributor to that space program. I was an inspector on the third stage of the Apollo rocket working for McDonnell Douglas.

And I have to tell you that most of the people that worked on that program at the space center would have done the job for free. They were thrilled to get paid for it. But it was a time not only to advance the greatest technological achievement in the history of mankind but it was a time when Americans were united. And, as you all pointed out, they were all united behind the program. And people around the world respected us and were united with us for that. It was the days that summer referred to as the Camelot era where you respected the President even if you didn't vote for him.

And so many of those times have passed, and I'm concerned, like many of the others that have spoken up about this before me about their experiences about the legacy for the young people that are going to follow us.

We know that, you know, space is important to our economy, our economic well-being. We know it's important to our technological advancement. We know it's important to our national security, national defense. It's the ultimate military high ground. And I think we all know from hearings we've had here before, ultimately, it's responsible for the survival of our species.

And so my question to the members of the panel is how you feel we can best continue the space legacy that was put forth with Apollo and inspire future young people and future generations of young people to follow?

Mr. FISHMAN. I think one thing when you talk to space entrepreneurs at all levels, people who are actually starting to work in space, it's possible that there's not a great framework in place yet for those folks to do their work. And so maybe one thing Congress could be thinking about is if we're going to have a space economy and if there's going to be a lot of operators in the space economy, as there is, for instance, in the digital economy today, maybe there should be a framework in which they have a real sense of security and predictability about what the rules are, who can do what, that kind of thing. I'm not sure that framework has been updated really very much since the era of Apollo. They signed a really important international treaty in the mid-'60s so that, as the Soviet Union and the Americans raced for the Moon, we were clear what was going to happen there. We weren't claiming the Moon; we were visiting the Moon.

And so when you talk to the folks who are doing this work now, there's a little trickle of curiosity and nervousness not about their own work but about the framework in which they're operating. And so it might be worth thinking about if we're going to have a vigorous space economy 10 years from now, what do we need to put in place now to make that possible and also secure.

Mr. POSEY. Yes, and it's so much a matter of dollars obviously. And someone mentioned earlier so many unfulfilled missions. We've had over two dozen missions to nowhere, over $24 billion that never reached fruition. Funding is a big problem. We used 4 percent of GDP back in the days of Apollo. Now, it's less than 1/2 of 1 percent. And the mission changes from Presidential Administration to Congress to Congress to Congress. I wish I had more time. Thank you, Madam Chair. I yield back.

Chairwoman JOHNSON. Thank you very much. Mr. Lamb.

Mr. LAMB. Thank you, everybody, for being here. And I wanted to kind of pick up where the last gentleman left off. I think the numbers I had were it was 4.5 percent of the Federal budget maybe as opposed to GDP. Do you know which one it was that we were spending on NASA back in the 1960s?

Mr. FISHMAN. Of the Federal budget.

Mr. LAMB. Of the Federal budget, OK, so still a major, major investment. And I think it's fascinating, Mr. Fishman, to talk about not just President Kennedy's speech but the fact that he actually put his money where his mouth was and made sure that we made this big investment and people kept making it throughout the 1960s and you clarifying that for us with the idea that we had 400,000 people massed around a single objective is just incredible and I think would be great today in this age where people worry about the future of work, where jobs are going to come from, how people are going to make good money and provide for their families with jobs. And I think most of the jobs we would be talking about for a space economy today and in the future would be pretty good-paying science-oriented manufacturing industrial jobs.

So I guess my question—and this is for really any of the three of you that wants to weigh in—is do we—in the combination today of Federal spending in the growing commercial industry of space here in the United States, do we have a similar level of capital investment to create those jobs and kind of create the size and strength of the space economy that we had in the 1960s? Between now it would be a balance of Federal and private investment. Does that exist or are we falling short of where we were back then?

Dr. JAKAB. Well, I think it's important to remember we tend to think of the Apollo era and up until the Shuttle era as purely a Federal program, that this—you know, NASA's government. But in fact much of the Apollo program was done by government contractors. The notion when we talk today about the new era of commercial space largely in the person of Musk and Bezos is really kind of misleading because there's always been commercial space. You know, the American industrial capability and research capability has always been part of it, and that was central to Apollo's success.

So what I think perhaps we can productively do today is sort of recognize that government and private partnership is critical to success. It always has been. It is now, and it will be in the future. So I think if we can somehow frame our understanding of the past in ways—again, my phrase about history rhyming, I think obviously it would be very different.

But of course the other component is, yes, the—President Kennedy made this, you know, very bold and dramatic statement and we kind of identify him with the enthusiasm for Apollo, but in fact he was not all that interested in space. It really became a significant component in the political context and the geopolitical context of the time.

So I think, again, in terms of history rhyming, we have an era now where our economic competitors and partners sometimes are one in the same, and we need to somehow marshal a national understanding of our place in the geopolitical economy and how we can——

Mr. LAMB. That's very helpful, and it's good to know. We in the Pittsburgh area where I'm from are proud that back then we had what is now known as Alcoa making the legs for the lunar lander, and we actually now have a new company spun out of Carnegie Mellon doing a lunar lander called the Peregrine, which is great.

So I guess my question more, though, is about the size of the overall capital investment, which then spins off all these jobs and innovation. So yes, there were government contractors in the 1960s, but they were being paid by the government with money that we allocated and planned for and invested. So if either Mr. Fishman or Dr. Miller have anything to say on the size comparison, that'd be helpful. Thank you.

Dr. MILLER. Yes, I do have something to say. I don't know if it's about the size comparison, but I think the growth of the commercial launch is an interesting example. And I guess what I mean by commercial launch there is that we're letting those companies follow commercial practices and guiding but—as a government, we're guiding but not—don't have a heavy hand in how they do things.

But an interesting thing that has happened is if the government can help these companies get a leg up because launch is hard and they can get more successful, they can start capturing other markets, which are not necessarily government-paid-for like commercial satellite launches, bring them back to our shores, which we lost a while ago, and then they get even better, and then we're buying, you know, a really refined product from them. And that's a great model, I think one we ought to——

Mr. LAMB. Thank you. And I'm out of time, so, Madam Chairwoman, I yield back.

Chairwoman JOHNSON. Thank you very much. Mr. Weber.

Mr. WEBER. Thank you, Madam Chair, and thank you for having this hearing. It's very timely for me. Last week, I had dinner with Jim Bridenstine, the NASA Administrator. I served four years in the U.S. House with him. So excited about the program and the possibilities going forward, so today's hearing is especially meaningful for me.

Ranking Member Lucas had an exchange with Dr. Miller and Dr. Jakab?

Dr. JAKAB. Yes.

Mr. WEBER. Yes. And he asked them what they thought was the most significant impact. And as I thought about that, how do we define this impact? I've got a term that I think might be of interest. It's called American togetherism. Now, Dr. Bera, Ami Bera, before he left he said American institutions of Congress actually worked together. That in and of itself is a miracle. Can I get a witness? Come on. And so I thought, you know what, you think about that, it was eight days, three hours, 18 minutes, and 35 seconds the mission was, and the whole collective world watched and was in awe of American togetherism. We need to get back to that. It was on display. It would not be the last time.

I want the world to always know, if you'll pardon the pun—there is space for American togetherism. We really need to remember that. It wasn't only a giant leap of mankind but also a giant leap of faith, but it was based on American togetherism, American technology, American know-how, and that spirit that we would do it no matter what. So perhaps we shouldn't call it the final frontier but the edge of the new frontier because the sky is the limit if you'll pardon that pun.

So I want to know, there's a couple things that happened. Mr. Fishman, you said three things that you thought were necessary to continue this trek if you will. You said bipartisanship or what I call American togetherism. You said bold and clear goals, and you also said the ability to move forward I think if I'm quoting you right. Was that what you said in response?

Mr. FISHMAN. Yes, sir. I think the third one would be to move forward consistently.

Mr. WEBER. To move forward consistently.

Mr. FISHMAN. A couple Members have pointed out——

Mr. WEBER. That works right into my question. So I appreciated that. And, Mr. Fishman, you all said to Bill Posey here, my colleague that has left, in your exchange with him that we weren't claiming the Moon, we were visiting, something like that. Is that right?

Mr. FISHMAN. Yes, sir.

Mr. WEBER. Do you think we ought to maybe make it our 51st State?

Mr. FISHMAN. That would actually be illegal, sir.

Mr. WEBER. OK. Well, I'm just checking. I'm just checking. You bring up an interesting thought process there.

The Apollo program served a single purpose, to land a crew on the Moon and successfully return them to Earth within the decade, which we all know we did with great pride and great joy. Follow-on plans by NASA were focused on building the shuttle to construct a space station that could serve as a waypoint for future exploration. We all know that history. As we saw after Apollo, plans get scaled back. There's that consistency you were talking about, Mr. Fishman, and capabilities are stripped away in order to save costs and maintain schedules.

So here's my question. Are there any lessons that we should heed from Apollo that we should heed as we embark on the next chapter of space exploration? Dr. Jakab, I'm going to start with you.

Dr. JAKAB. I would say, again, we've talked a lot about common goal and focus and marshaling our resources toward a common goal, but I would perhaps modify one—in answering your question, modify one comment you said. Yes, the goal was to put humans on the Moon and all of that, but the goal was also to do good lunar science. And lunar science continues not only with current probes but also the data that was acquired during the Apollo era continues to be used to do lunar science. So our focus in these missions is not only a commercial one, not only one of sort of establishing America's prowess in space, but also to do good science and understand our universe. And I think that's——

Mr. WEBER. OK. I'm running out of time. So other than the National Air and Space Museum, I'm going to jump over here to Dr. Miller, how do we do that? How do we make that preeminent? How do we keep that in the forefront?

Dr. MILLER. I think the key thing is this time it's got to be to stay. There's a sustainment element which I think, as we learn how to do that, we can apply that directly to what we do here on Earth. I think that's a key piece.

Mr. WEBER. I think that's a plan.

Dr. MILLER. And I think that the—another thing we've got to get our—all intent aligned is imagining a day without space. I think it's hard for people to do it. It's out of sight, so it's out of mind. But just the things that you lose if for 1 day you shut it all off: Financial transactions, global data and voice networks, GPS, weather forecasting, farmland management, pollution and deforestation tracking, missile launch detection. All these things go away.

Mr. WEBER. Those are the accomplishments that we want to keep in the forefront.

Madam Chair, I'm a little over time. I appreciate your indulgence. I yield back.

Chairwoman JOHNSON. Thank you very much. Ms. Stevens.

Ms. STEVENS. Thank you so much. We've been doing a lot of talk about history today, and in fact, if it was 50 years ago today just 1-1/2 hours ago, we would have witnessed the rocket taking off. And it was as if humanity was taking first and new breaths, that we were being reborn as we were making our way to the Moon landing. And the entire world was in awe of this country.

So I was born about 15 years after we landed on the Moon, and I'm not even necessarily thinking about myself. I'm thinking about those who were taking those first breaths today who were born 50 years after we landed on the Moon. So you get some history, backgrounds, some great scientific backgrounds. I'd like to ask each of you what you think our moonshot of the next 50 years is, be it an arrow or another technological area?

Dr. JAKAB. Well, I think one obvious moonshot type of project that we need to do is obviously climate—dealing with the climate. Our world is changing, and I don't put that in the context of good things or bad things. This—it's—the world is changing, it is having impact, and obviously that's something that affects the entire world. So if there's anything that the world could unify around is to developing solutions. And it's not a single bullet kind of thing that's going to, you know, doing something about climate change. It's addressing the impacts in broad ways that have not only economic but also geographic implications.

And so I think looking retrospectively, we look at—you know, space allows us to look at ourselves, look at the Earth as well as looking out, and perhaps one way to advance our looking out is to look at—look back at the Earth.

Ms. STEVENS. Well, there's a psychology to it. And, you know, I'm from Michigan, and we know a thing or two about innovating in

Michigan and changing the way people do things and transport things and connect to one another. And we implore ourselves in the body to ask ourselves this question, challenge the notion of what defines American greatness. And it simply codified within our great ability to innovate.

And as my colleague from Pennsylvania brought this hearing in his questioning to the notion of jobs and future employment and technical workforce, I think we've got to ask ourselves about the return on investment (ROI) that a great new deal effort that in today's dollars is $600 billion. What else have we or could we invest in at that scale that would bring the ROI that we saw from the Moon landing not only to our psychology but also to our economy?

Dr. MILLER. You know, I think about—having spent 2-1/2 years working at NASA, and the Technology Transfer Office was in my office, it was fantastic to see all the things how—not only the indirect impact of Apollo and all that but also the direct impact on today.

Some examples, solar panels were built for space, and now they are perhaps one of the largest renewable sources of energy, huge terrestrial impact. There's a NASA Spinoff magazine which will list all these for you, but, for example, before some of the shuttle missions flew, in desert regions it was hard to find where water was, you know, during a humanitarian crisis. Now, based on NASA technology, we can find it, we can drill once and find it. We know where the water is in the desert, and 99 percent success rate.

So these are—agriculture, when you—when the farmer wakes up today, they don't milk their cows first—maybe they do—but they actually log in. They can see to sub-resolution on individual fields where I need water, where I need fertilizer, where I might have an infestation. That allows us to apply resources much more judiciously, helps with sustainability. These are real things that are directing—that are impacting beneficially what we do on Earth right now due to what NASA does.

Ms. STEVENS. Mr. Fishman, do you want to chime in here? And thank you so much for your great contributions and your written words and your dedication to primary resources with your tech.

Mr. FISHMAN. So just briefly, one thing that's important to distinguish, Thomas Paine, who was the Administrator of NASA at the moment that Apollo 11 was launched, said, you know—there were protesters at the launch site the day before Apollo 11 on July 19. The Reverend Ralph Abernathy led a group of protesters who said you're launching people to the Moon, but there are people in America who don't have enough to eat. How do you resolve that? How can you explain that?

And it was an interestingly different era. The Administrator of NASA came out, he was at the Cape of course, and met the protesters. And he listened to them. And then he spoke to them and he said, you know, going to the Moon is different than solving the problems of poor schools or the problems of poverty and hunger. When we engineer a solution to get from orbit in the Moon to the surface of the Moon, it works exactly the same every time. Poverty does not work that way. To the protesters he said if we could not launch tomorrow and thereby solve the problems back on Earth, no one at NASA would push the button.

And so I think it's important to appreciate that a quote/unquote "moonshot" needs to operate in the context of the difference between engineering and social systems, which need their problems revisited every day.

Ms. STEVENS. Fabulous. Thank you, Madam Chair. I yield back.

Chairwoman JOHNSON. Thank you very much. Mr. Baird.

Mr. BAIRD. Thank you, Madam Chair. And thank you, witnesses, for being here today. You know it's exciting to me to be having this conversation about going back to the Moon and maybe beyond, and so that's very encouraging to me.

I guess my question goes to all three of you. My alma mater is Purdue University, and in my district there are a few notable alumni that we like to take claim to, one of those being Neil Armstrong. But 50 years ago, the world united to witness and celebrate that giant leap for mankind when Neil Armstrong took the first step to the Moon.

So when we return to the Moon in a few years, what do you think the impact will be? And I know some of you have already addressed that, but I would like to give you another opportunity. And then what additional advancements would you anticipate that we might find when we do that? You can start, anyone of you.

Mr. FISHMAN. Well, I think one thing to remember, we've talked about clarity of mission in terms of going to the Moon in the 1960s, but there was also clarity of purpose. And so I think if the United States is going back to the Moon, I think one thing we need to be able to do is explain both to ourselves and to the public why we're going back to the Moon and what that will accomplish and what the next step after that is, what's the—not just here's what we are doing but to be able to make the case for why we're doing it and what value it has. And I think that's a really important element of the next stage of development.

Dr. MILLER. I think also Gene Cernan goes on that list from Purdue.

Mr. BAIRD. Say again?

Dr. MILLER. Gene Cernan I think also goes on that list as a graduate of Purdue——

Mr. BAIRD. Oh, yes.

Dr. MILLER [continuing]. So just checking. But, you know, I think—let's zoom back to the 1200s. Marco Polo opens up trade routes through China. I guess 1400s or 1500s Magellan sets out to circumnavigate the world. I'm sure there were a lot of people saying why are we doing this, you know, what a waste of resources, you know? But it changed everything. And so every time civilization has crossed a big river, gone over mountains, sailed the oceans, on average, you know, civilization has advanced.

Space is the new ocean. We can't predict all the steps through it, but it's—we're—in 50 years I think the biggest thing is we're going to look back and say what took us so long because everything will have changed if we're willing to do the mission.

Dr. JAKAB. Just sort of following on that, you know, the quote that if I knew what I was going to find, we wouldn't call it research. And I think we always have made investments in things that we couldn't anticipate what the outcomes would be, multiple outcomes and so forth, so I think we somehow have to marshal a commitment to research.

And, again, I think someone—one of the Members mentioned earlier about, you know, every few years the mission changes, but I think we need to somehow establish, independent of changing leadership and changing political establishments, that research and exploration always has a place in what we do and very much associated with a free society to pursue those goals. So that to me is the goal. How we do it is perhaps more complex.

Mr. BAIRD. Thank you. And then, Dr. Miller, you mentioned—and I have a background in agriculture, so when you talked about placement of fertilizers and chemicals and all that has been a tremendous advancement in the last decade. And a lot of that originated with some of the space program technology. Any other thoughts you'd like to elaborate or any one of you? I've got about 40 seconds, so——

Dr. MILLER. You know, I think the biggest impact is I know firsthand that there's a wealth of the younger generation that are pursuing degrees in engineering and science that just have a passion for space. And sometimes I think the most powerful thing I can do as a teacher is give them the resources and get out of their way. And I'm just amazed about what they're able to accomplish. So if we can get out of their way, all the better.

Mr. BAIRD. Thank you. And I'm out of time and I yield back.

Chairwoman JOHNSON. Thank you very much. Ms. Horn.

Ms. HORN. Thank you very much, Madam Chair, and thank you to our witnesses on such an important and exciting panel. We've covered a lot of ground today, and I want to circle back to a couple things because ultimately we are both looking for inspiration and guidance. Those of us who were born after the Apollo era have experienced a different world thanks to the investments that we as a Nation and then bringing in other international partners have made. And the world that we live in today is fundamentally different than it would have been had we not made those investments.

I think, Dr. Miller, to your point, basically everything around us from the phones we carry around to precision farming to medical technology to the way we live our lives is so utterly integrated into the follow-on technological advancements that came about as a result of Apollo that some of them were the results of the known unknowns, things that we knew we would have to develop; and others, the unknown unknowns that we had no idea would be follow-ons and would emerge. And we've seen this amazing investment both have scientific benefits but also technological benefits and spinoffs into private industry that found a way all of its own. And we're looking forward into the sustainability.

And I also noted, as many of my colleagues did, Mr. Fishman, that one of the great things about space is that it is not a partisan issue, it is bipartisan, but the need for clear goals and the ability to move forward. And as we do that, because it has been 50 years since we first landed on the Moon, we are in a rebuilding and restarting period in this new exploration so the need to have a sustainable and clear pathway is critical.

But one of the things Apollo taught us was the value of taking audacious and yet intentional risks. Because NASA's relentless pursuit of their efforts to go to the Moon but also to mitigate those risks and learn from the failures and the shortfalls through testing of anomalies and through repeated and iterative process was critical.

So I'd like to ask the panelists, looking back at these audacious risks, how did the Administration and the public discuss this risk, and how did the public acceptability of the risks that we engaged in and how that has changed and how we can reengage this conversation with the public around risk?

Mr. FISHMAN. Well, I think one of the most important moments in that whole conversation inside NASA and in the country was the Apollo 1 fire. In January 1967, the first three Apollo astronauts who were scheduled for launch were in their capsule. They were doing a rehearsal. There was a spark and a fire. The capsule was sealed. It was also poorly designed, and the astronauts died.

There was investigation both inside NASA and in Congress. And in fact the conclusion was that the workmanship on the Apollo capsule but across the whole Apollo effort was pretty slapdash. Those three astronauts died most likely because two wires that shouldn't have been rubbing together were rubbing together and the insulation had rubbed off. They took a finished Apollo capsule and took it apart at the same time they were taking apart the one that had caught on fire, and they discovered the same kind of workmanship flaws in the finished capsule that hadn't been used yet.

And the fire was a kind of dramatic shift in the culture of the Space Agency, a shift that really drove this idea of risk management. Things have to be done with incredible care if we're going to safeguard this mission, which is a little different than other things.

And so I think the way NASA approached this at that time was to say this is the kind of mission in which one thing going wrong can put everybody at risk, but also we've got 400,000 people who know that more vividly than ever before. And so I think that really impressed on people the idea that anything going wrong was a gift if it went wrong on Earth. If you tested it and it failed, that was information you needed to use. And before the fire, the Agency didn't have that kind of view. And to be honest, in the years after Apollo, I think space culture drifted in a different direction, in a kind of operational direction. And so understanding—letting the public understand the risk but also making sure that you're investing the right level of attention to manage it inside are really important.

Ms. HORN. And I'm afraid I took up some time at the beginning, so we don't have much left, but I think the bottom line is attention to detail and risks and testing moving forward and understanding that space is always going to be hard and that we need that expertise moving forward as we return to the Moon and beyond. Thank you, Madam Chairwoman. I yield back.

Chairwoman JOHNSON. Thank you very much. Mr. Gonzalez.

Mr. GONZALEZ. Thank you, Madam Chair. And thank you to our distinguished witnesses for being here today to commemorate this incredibly important day.

The cultural, political, and scientific impact that the Apollo 11 mission has had on our country is remarkable. The images of Neil Armstrong's first steps on the Moon are iconic and represent an important milestone not just in American history but in human history.

I'm privileged to serve as Co-Chair of the bipartisan NASA Caucus here in the House with my fellow Ohioan Representative Marcy Kaptur and Committee Members Horn and Posey. The caucus was created to educate Members about the many diverse NASA initiatives and support NASA efforts to advance scientific research and technology. Being a part of the NASA Caucus is especially rewarding for me because of Ohio's unique relationship with the space program. Both Neil Armstrong, the first man to walk on the Moon, and John Glenn, the first American to orbit the Earth, are proud Ohioans. Additionally, northeast Ohio is home to the NASA Glenn Research Center, which focuses on developing innovative technology to advance NASA's missions in aeronautics and space exploration.

I had the privilege of visiting a few months ago and have no doubt that the groundbreaking technology being researched and experimented with at NASA Glenn will help to shape the lives of Americans in the future.

With that, Dr. Miller, in your testimony you discuss how the use of a portable computer was a novel idea at the time of Apollo 11 and virtually unheard of. The rise of the smartphone and Digital Age in Silicon Valley has rapidly changed our world so that a portable computer is now completely commonplace. We can debate whether that's a good thing. But as former NASA Chief Technologist, can you discuss some other notable scientific and technology advancements that NASA has played a part in and how they have helped to shape the lives of everyday Americans?

Dr. MILLER. Well, one thing I might—I should mention is, as Mr. Fishman was talking about learning that failure is not an option when life is at risk, the—and learning how to do—how to really up our game on doing reliability and mission assurance and in fact that's an interesting thing in the—at Aerospace Corporation, that's a huge role that we do is learn from the lessons from Apollo and how to do mission assurance properly and bring that everything we do in space. And, you know, that's a very important sort of spinoff——

Mr. GONZALEZ. Yes.

Dr. MILLER [continuing]. That has had a vast impact on everything.

Other—you know, one of the ones that surprised me is that—this isn't technology but it's something like 80 percent of baby formula today has an additive that was developed by NASA. The—every smartphone, which we probably all have that phone, is just these—you know, these things that were developed in order to make the crew more capable or robotic missions more lightweight and therefore could put more instruments on them, more capable, you know, all that miniaturization, low-power work, and the impact on health of astronauts impacts health of our people, the—those are all very dramatic impacts.

Mr. GONZALEZ. Yes, so for me personally the spinoffs are unbelievable. It's incredible, right? I mean, I think as an everyday citizen, you don't think about NASA as being in your smartphone necessarily or in baby formula.

Dr. MILLER. Right.

Mr. GONZALEZ. But when you look at everything that NASA has had an impact on, it's remarkable.

Dr. MILLER. Yes.

Mr. GONZALEZ. And I'm just thrilled that we have NASA in this country and in my home district.

Dr. MILLER. I was going to mention one of the things—I had worked with NASA for many years, but what really blew me away when I got there was its brand.

Mr. GONZALEZ. Yes.

Dr. MILLER. When I'd go internationally to speak, there would be packed auditoriums streaming to other auditoriums. It's just everyone comes out and wants to hear what NASA is doing. And the thing is that's a very strong element of diplomacy. You know, that NASA brand worldwide is second to none in my opinion.

Mr. GONZALEZ. Yes. Let me ask you this——

Mr. FISHMAN. Can I——

Mr. GONZALEZ. Oh, sure. Go ahead.

Mr. FISHMAN. I just wanted to say the week before the Apollo 11 launch, Fortune magazine did a cover story saying one of the great contributions Apollo has made to American society is big project management, that if you look at how NASA was able to manage prime contractors in all 50 States, 400,000 people, and get the job done, it all fit together, it all worked, and it often had to work perfectly, that that management scheme is really important going forward. We have big things we want to do. Understanding how to do them without letting them run out of control is a really valuable lesson as well.

Mr. GONZALEZ. I think it would actually be really interesting to look at what the regulatory environment looked like back then and what the contracting process looked like back then and compare it to what it looks like today. I would bet that it's a lot harder today. I think that would actually be very interesting. I'm also out of time, so with that, I yield back.

Chairwoman JOHNSON. Thank you very much. Ms. Hill.

Ms. HILL. Thank you, Madam Chair, and thank you all for being here. I'm really excited about this.

My district is the proud home to many Edwards Air Force Base employees and to a portion of the base. NASA's Fight Research Center at Edwards Air Force Base, which is now called the Armstrong Flight Research Center, made a number of contributions to the NASA human spaceflight program during that era, from the X-15 rocket plane hypersonic research program to the lunar landing research vehicle, both of which had a direct impact on the Apollo missions.

The first flight of a lunar landing research vehicle was in 1964 on Edwards, and these vehicles were later used at Ellington Air Force Base to train Apollo flight crew, including Neil Armstrong.

On a personal level, I mentioned to you earlier, Mr. Fishman, that my grandfather worked extensively on the altitude control thrusters for the lunar lander. From 1961 to 1970 he worked on those and for—and I'm particularly excited about this hearing because of both of those connections.

So today, I wanted to talk about some of the lessons learned from this previous experience. And a question that a lot of people ask me and I even wonder about myself, if we were able to do so much of this work in such a short period of time with the technology of so long ago, why is it so hard for us to even make partial progress on a similar mission today?

Specifically, to all witnesses, in 1957 Wernher Von Braun and his team at the U.S. Army Ballistic Missile Agency, began the development of the heaviest lift ever built, the Saturn I. This included developing a brand-new F-1 Rocketdyne engine, as well as solving numerous engineering challenges. Following the establishment of NASA and the Presidential direction to go to the Moon, plans were made to use five of the F-1 engines for the first stage of the new human-rated engine that would take humans beyond low-Earth orbit (LEO), the Saturn V. It first launched in 1967 just 10 years after starting development and took humans to the Moon just a few years later. Saturn V remains to this day the most powerful rocket ever launched and can carry more payload to LEO than the envisioned SLS Block 1B.

So how was NASA able to build the largest launch vehicle ever seen in a short and rigid timeframe and yet SLS is plagued by delays?

Finally, what lessons from constructing this rocket can we apply to similar large-scale projects that we're attempting to do today?

Dr. MILLER. I was also going to add I think it was the F-33, which is a—was a test plane at Edwards was the first plane to have digital flight controls right out of—and that's gone into other planes now.

So back to your question, you know, I think—well, one of the things is NASA's at one-tenth the budget that it used to be, and there were other organizations like the early form of DARPA (Defense Advanced Research Projects Agency) that were involved in F-1 engine development and things like that, so there were—you know, we aren't at the same level of resource.

The other thing is, you know, I think—I think NASA gets a lot of help from outside. It's a great Agency to work with, but I think, as people have been saying before, guidance, priorities, vision keeps changing. And it's changing at a pace that is faster than NASA can execute and even faster than the decade that Kennedy gave NASA back then with 10 times the resources.

So, you know, I think the real solution is some combination of more funding but also give them a—give NASA a mission that we can all believe in and get out of their way.

Mr. FISHMAN. Clarity of purpose.

Dr. JAKAB. Yes, I mean, I think we've said it in a variety of ways both in contemporary times and historical times. Clarity of purpose, clear mission, resources, and allowing it to happen. I mean, it's perhaps a little simplistic formula, but sometimes, you know, the simple way is——

Ms. HILL. Yes, Occam's razor. I come from the nonprofit sector, and what you're describing sounds a strategic plan, so, you know, maybe that's something to work on. And clearly, you can't do that without the direction that has to come from Congress and from the Administration.

Another thing is that one takeaway I have in talking with my grandfather is how much of a catalyst this work is for national pride. The moonshot gave Americans something to believe in, and that belief paid off in the enduring impact you've talked about into scientific discovery and groundbreaking commercial applications.

But I also think of how badly we need unity as a the country right now. And a big part of the push around space exploration in the past had to do with the cold war and the sense of an immediate and deadly threat. If people don't believe that we face such a threat right now, can we still achieve that national pride and unity and prioritization if we don't—you know, 10 times the resources had to do with believing that this at least was in part a national security defense investment.

Mr. FISHMAN. I would just say the point of going to the Moon wasn't unity. The sense of national pride and worldwide pride came as we achieved it. And so I think that's important to remember. It was born as a Cold War tactic, but by 1969, by 1972 it had actually—the mission itself had become something different that we don't think—we don't look at Aldrin and Armstrong, we don't look at the guys driving around in a lunar rover and think there they are beating the Russians. We think, wow, what an incredible achievement.

And so I think getting the mission right and the mission of NASA itself right comes before hoping that people will then unify behind that. I think the right mission does unify people rather than the other way around.

Ms. HILL. Thank you so much. I know I've exceeded my time.

Chairwoman JOHNSON. Thank you. Dr. Babin.

Mr. BABIN. Yes, ma'am. Thank you, Madam Chair. Thank you. We appreciate you expert witnesses.

It's funny that you mentioned—I think it was you, Mr. Fishman, mentioned the vision a while ago or maybe it was Katie, I don't remember, but over here on the right on the wood panel there is Proverbs 29:18, and it says, "Where there is no vision, the people perish." And with the right vision, which we had for Apollo, I think we can do that again. And so I think it's very important that we have a vision when we think about returning to the Moon in the future, in the hopefully not too-far-distant future.

Really some interesting things I want to tell each and every one of you. Thank you so very much. You know, 50 percent of Americans did not think it was worth the money to go to the Moon back 50 years ago. And then we've heard all morning about the just list after list, I think 6,000 innovations, inventions that we've derived from our space program that we use every single day, and so I think it's very, very important that we have a future endeavor like 2024.

But I proudly represent the Johnson Space Center (JSC) in Houston and serve as the Ranking Member of the Space and Aeronautics Subcommittee. And Johnson was home to NASA's mission control center, as all of you know, and played pivotal roles in the Apollo program. And from the first landing on the Moon by Apollo

11 to the expert troubleshooting of Apollo 13, JSC mission controllers were centerstage for history.

Can each of you take just a few seconds and discuss the unique capabilities and accomplishments of NASA's mission control and the importance of developing a skilled cadre of flight control professionals? We'll start over here, Dr. Miller, you can go ahead and go first. You were quick on the draw.

Dr. MILLER. Jumping at the mic, sorry. I'm going to fast-forward to mission control today. I want to point out something that I think a lot of people may not see in terms of mission control and operation of the International Space Station. We've got—it's an International Space Station. We've got allies, we've got colleagues. It's really a—keeping that multinational consortium together, and a lot of that is done with mission control and the handoffs with Roscosmos and with JAXA and ESA. That is politically amazing to me.

Mr. BABIN. Right.

Dr. MILLER. And I think when we developed this vision, this idea of helping to lead our allies and our other spacefaring nations on this mission I think could really pay a lot of benefits to us. Like maybe not a lot of people know that the MOM (Mars Orbiter Mission) mission, which was the Indian mission to Mars, they're one of four countries I think that have successfully orbited Mars. And, you know, that kind of leadership that the U.S. has played I think is a very important part. It's—that's beyond the technology but I think is—should be absolutely part of the vision.

Mr. BABIN. All right. Thank you. Thank you so very much. I'm going to skip to the second question. JSC is also home to the Lunar Sample Lab Facility. Can you explain why this facility was so important for the Apollo missions and how it will be used for our return to the Moon, one of you there? Dr. Jakab.

Dr. JAKAB. As I alluded to earlier, lunar science is also—you know, was a critical component of that, and we still have many lunar science missions going on, lunar reconnaissance orbiters, and others, as well as international efforts to do that. Again, exploration is as much about looking forward as it is about looking back and understanding origins of the Solar System and where our species came from and all of those large questions.

You know, we look at the space telescope and the near-term coming launch of the James Webb Space Telescope, and those are time machines. You look out into space——

Mr. BABIN. Right.

Dr. JAKAB [continuing]. And you see history. So I think it's important to understand that the—in terms of lunar science, not only the samples that we have from that time period, which are still vital resources for planetary sciences and research, continue to be of value. So while we talk about inspiration and exploration and human spaceflight and those components, which are critically important to stimulating all the things we've talked about, the scientific mission is still paramount.

Mr. BABIN. Thank you. I want to get in one more question here before the end. We think of Apollo as a success, but up until Apollo 11, we trailed the Soviet Union in almost every accomplishment in space. Competition fueled our national ambition, as Mr. Fishman had said a while ago. What if anything drives our current space program? Are there any similarities between the Soviet Union of the 1960s and the China of today? Would one of you all like to answer that?

Mr. FISHMAN. I think the rivalry then was much more vivid and acute. One of the things that's really true is that the Chinese people and the Chinese government is very good at laying out an 18-year plan and then actually doing year 1, year 7, year 11, and year 17. In America, we lay out in 18-year plan, do nothing for 15 years, and in year 16 we say, whoa, we better get started. So the rivalry is different.

I think one useful thing is to pause and imagine what would've happened if the Soviet hammer and sickle had been the first flag on the Moon and how that would've made not only us feel but the whole world. That was a banner of authoritarianism and oppression. And so I think it's—one way to think about rivalry in space is to imagine what would happen if great achievements are done by nations that the United States considers its rivals when we could have done them but simply elected not to?

Mr. BABIN. Well-stated. Thank you, and I yield back, Madam Chair. Thank you.

Chairwoman JOHNSON. Thank you very much. Mr. McNerney. Oops, Mr. Tonko.

Mr. TONKO. Thank you, Madam Chair.

It's an honor to mark the 50th anniversary of the Apollo 11 mission. I was in school when Sputnik traversed America's night sky and inspired our race into space. It was American engineering, science, and pioneering resolve that went out against our Soviet rivals and put the first human footprint and American footprint on the surface of the Moon. In those years of striving and investing and innovating transformed the world of science, technology, engineering, and math with America leading the way.

As one of the 650 million viewers who witnessed Neil Armstrong's first steps on the Moon, I am forever affected by the memories of that day. It inspired me to see that, with vision, resolve, and essential resources, America can always lead the way in exploration, research, and development. The only question is whether or not we will.

Like so many fans of America's push into space, I'm excited about the upcoming launches of the Mars 2020 rover and the James Webb Space Telescope. Even more, I am excited by the impact these missions will have on the leading edge of so much scientific discovery continuing to engage the public and inspire a new generation of scientists and engineers.

And I often tell students in our New York Capital Region that learning STEM can make you a scientist who learns about secrets about our universe, maybe the astronaut who lands on Mars or the doctor or researcher who makes healthy passage on long spaceflights possible, or an engineer who invents the new technology that paves the way for space travel that will take us far beyond the boundaries of our own galaxy. We must continue pushing for America's innovation and exploration with the same determination that brought our astronauts to the Moon 50 years ago.

Now, to reflect on that historic moment when the world held its breath and Neil Armstrong took that first step, let us remember that it falls to us to build on that scientific legacy and to do everything we can to foster ingenuity and discovery now and for generations to come.

So, Dr. Miller, how could the innovations that brought Americans to the Moon that, 50 years ago, still contribute to discoveries that will be made by future generations of scientists?

Dr. MILLER. Well, I think it's happening right now. I'm glad you mentioned a lot of the accomplishments that are going on in the Science Mission Directorate at NASA. I mean, there's been a wealth of innovation there that has led to very dramatic discoveries.

You know, we know the—it was a great accomplishment for the Chinese to land on the far side of the Moon, but we got to remember, the United States was the first to every planet except for our own—that was Sputnik—but all—and even Pluto. And in fact, we have multiple spacecraft that have departed the Solar System. James Webb is going to look back to first light in the universe. I mean, these are amazing accomplishments.

I'll give you another example. The exo-solar planets that are—that we're finding, the exoplanets, when I was in school, there were nine planets. Then I went down to eight. It's going in the wrong direction. And now it's 4,000 and counting dramatically. And we're starting to see all kinds of ways in which solar systems can evolve. And that informs us about our own Solar System.

There is so much richness in all the various things that NASA does even in—on the aeronautics site as well that, you know, there's something for everyone.

Mr. TONKO. Well said.

Dr. MILLER. And it's great to see that.

Mr. TONKO. Mr. Fishman, the lunar descent and landing were an extremely intense time. There were alarms going off and Neil Armstrong, the commander, had to take manual control over the landing. At one point his heart rate was, I believe, 150 beats per minute. Can you describe just how close Apollo 11 was from failing to reach the Moon's surface safely and the planning and designs that made it successful?

Mr. FISHMAN. It took 13 minutes to get from orbit to the surface of the Moon. The first 3 minutes went great. The last 10 minutes were a cascade of problems. The problems might have prevented Armstrong and Aldrin from landing successfully. They had to find a new place to land because the landing site turned out to be a 60-foot-deep crater with boulders the size of cars at the bottom. They were worried about running out of fuel. They were burning through 1,000 pounds of fuel every 30 seconds. And then the computer started announcing that something was wrong in the spaceship.

It turned out that the computer was working perfectly. It was receiving errant signals from another part of the spaceship, and the alarm, it was sounding literally meant I am doing my job just fine. Some other part of your spaceship isn't working right. You should check that out.

And I think Armstrong and Aldrin—at one point the computer screen in the lunar module went blank for 10 seconds. They were only 1,000 feet from landing. Armstrong and Aldrin never mentioned that until they were back on the aircraft carrier in the Pacific Ocean. Imagine the dashboard of your car going blank at a critical moment like that.

And that's what it's like to be an astronaut. There were big problems, but they had trained, and they also had the kind of character that sort of—they said—Armstrong said later there was a lot of chatter about whether we were going to board or not. Let me be really clear. We were putting that ship down on the Moon, so——

Mr. TONKO. Well, thank you. I think it's important for us to salute that character this week as we celebrate that 50th anniversary. And with that, Madam Chair, I yield back.

Chairwoman JOHNSON. Thank you very much. Mr. Olson.

Mr. OLSON. I thank the Chair, and welcome to all of our witnesses.

As a guy who grew up about a mile and a half from the Johnson Space Center, Apollo 11 has a very special place in my heart. We all know it started at Rice University, my alma mater, September 12 of 1962. President John F. Kennedy, first of all, he popped Rice. He asked, quote, "Why, some say, the Moon? Why choose this as our goal? And they may well ask why climb the highest mountain? Why fly the Atlantic? Why does Rice play Texas?" end quote. That last question has never been answered since 1962.

But he also said, "We choose to go to the Moon. We choose to go to the Moon. We choose to go to the Moon in this decade and do the things not because they're easy but because they're hard." You mentioned Apollo 11's descent. They were less than 10 seconds away from running out of fuel and having to abort that mission. Apollo 12 was hit by lightning on ascent. We all know about Apollo 13. And Apollo has been such the inspiration not just for Americans but to the entire world.

My question is about how can we learn, first of all, we have talked about STEM. That's cool. That's very valid. I mean, people got excited. I saw that firsthand living there. We had engineers just pouring in from all across the world getting involved in going to the Moon and beyond. But what impacts did Apollo 11 have on other spinoffs, Mr. Fishman, came from Apollo 11 that's helped the world right now that we should celebrate? And not Tang or Velcro.

Mr. FISHMAN. I think what we've tried to say here today is that space is integrated into the way we live. Dr. Miller said imagine a day without space. Well, you couldn't run a farm, you couldn't run your email, you couldn't get a weather forecast. You know, Walmart tracks its trucks using satellites every minute of every day.

And so I think what the race to the Moon did was accelerate a digital economy that is the U.S. economy today. And so the question is—but no one said in 1965 if we go to the Moon, all this other stuff will happen on Earth.

Mr. OLSON. Yes.

Mr. FISHMAN. And so I think in some ways one of the most valuable lessons is that a stretch goal of this sort, which seems almost impossible, creates in its wake not just the achievement of that goal but all kinds of other accomplishments and, as Dr. Jakab has said, incredible breakthroughs in just understanding how the world works, which are invaluable.

Mr. OLSON. And also how the human body works. Dr. Miller, do you want to add anything about the benefits of landing on the Moon, the Apollo missions?

Dr. MILLER. You know, when Mr. Fishman was just talking there, it reminded me of some car ad where they said it's not the destination, it's the ride, it's the trip. And—did I get that right? And, yes, you don't know what's going to come out, but I said in my comments that really the amount of innovation you're going to see is proportional to the length of that stride you're going to make. So if we just do little things, we're going to have some modest innovation. I think we got to take big steps, big strides like we did in the 1960s.

Mr. FISHMAN. Let me add one point.

Mr. OLSON. Sure.

Mr. FISHMAN. You know, the ability to launch inexpensively right to low-Earth orbit, right now, every square foot of landmass on the Earth is photographed every single day by a private company, by planet.org. They're using small satellites, and they literally photograph the Taj Mahal and the Capitol of the United States and Cape Kennedy every single piece of land——

Mr. OLSON. Johnson Space Center.

Mr. FISHMAN. Johnson Space Center, any place you want to name. Every single square foot of landmass on Earth is photographed every day. That's how we know what the North Koreans are up to, not because of the NSA or the CIA but because photograph the ports and the nuclear sites and the rail yards and the truck parking lots. We photographed them yesterday, we photograph them today, we photograph them tomorrow. That innovation is possible because launch costs have come down.

And so as the space economy gets going, you're going to see this incredible blossoming of innovation because people will start saying what if we do this, what will be the wonderful consequences? And so I think enabling that kind of innovation is really important.

Mr. OLSON. And I'm out of time. I'll submit questions for the record about AI, and its role in going to Mars and beyond. But thank you, thank you, thank you. And I'll close by saying, as I said when I was a 7-year-old boy, fly me to the Moon. I yield back.

Chairwoman JOHNSON. Thank you very much. Mr. Perlmutter.

Mr. PERLMUTTER. Gentlemen, thank you for your testimony today. And, as you can see, we're all loving this. The three of you actually gave me goosebumps, and I want to talk about a fourth person who testified a few weeks ago for us. But, Dr. Miller, you were talking about the ownership and the engagement of young people and the ability to take advantage of those brilliant youthful minds.

Mr. Fishman, you talked about the inspirational component of all of this and the striving to go beyond, you know, where we'd been before.

And, Dr. Jakab, you talked about the teamwork. I mean, I did get goosebumps as you were talking about the apocryphal janitor helping get us to the Moon. And that's what this is about.

We talked about the tangible results in all the spinoffs, and we talked about the intangible a lot as part of the piece that brings Democrats and Republicans together to do something bigger than any of us, a lot bigger than any of us.

We had a young woman who came in and testified a few weeks ago. She had the brilliance to knit together thousands of signals taken from all around the world to draw the black hole. And she was inspirational, just as you gentlemen are, in testifying to us to really try to find the ability of this Nation to do something bigger again.

Now, you know, Ami Bera was joking around, but I've been very single-minded in terms of a bigger mission, one that requires consistency of purpose and direction and ingenuity. There's an element of competition. You know, we've talked about rivalry or national security or whatever between the Russians and America back then, but we have that element today.

But I see this as being something that's going to be international in scope, public-private in nature, and, you know, if we can get our—when we get our astronauts to Mars by 2033 if not earlier, it's going to take the whole world to do it, and it's going to take a lot of private effort as well but led, in my opinion, by NASA because of its brand and its unbelievable staff.

So I'm just going to turn it—I have no idea what you guys are going to say, but what do you think about getting to Mars by 2033?

Dr. MILLER. Well, one thing I'll mention is that's—I'm sure that's why you put that on there because 2033 is—it's not easy to get to Mars, but that's one of the easiest times relative to——

Mr. PERLMUTTER. Right, because the orbits are closest——

Dr. MILLER. Right.

Mr. PERLMUTTER [continuing]. For a long time.

Dr. MILLER. Yes. Yes. And so, you know, I think what always helps with the space program is a sense of urgency. And, you know, it's good to have deadlines as long as they are deadlines that we can reasonably make and we can put the resources behind them and so forth. And, you know—so I'm all in favor of 2033.

Mr. PERLMUTTER. Mr. Fishman, what do you think——

Mr. FISHMAN. Well, you——

Mr. PERLMUTTER [continuing]. As a historian and a writer?

Mr. FISHMAN. You said something interesting. You said it will take the whole world. If you go back and look at John Kennedy's speech in May 1961, the first go-to-the-Moon speech, there's a wonderful passage at the end where he says if we succeed in putting an astronaut on the Moon by the end of the decade, it will not be that astronaut who went. It will in fact be all of us in America because, if we're going to do it, it's going to take us all. We've heard from the janitor.

The spacesuits were sown by hand. The circuitry in that advanced computer we've talked about was woven by hand because there was no other way of manufacturing it. And so you said it will take the whole world. I think Mars is the kind of project that will take the whole world. There are not many countries that could galvanize that kind of project, and that would be a different undertaking than Apollo. But I think the idea that getting everybody on board is a really good one, and it's an echo of what Kennedy said in May 1961.

Mr. PERLMUTTER. Dr. Jakab—and I do want to acknowledge my friend the former Governor of Florida because after he listened to the three of you testify, his one-word was inspiration. But, Dr. Jakab.

Dr. JAKAB. Well, I think when we talk about getting to Mars or other bodies in the system and identifying that as a goal, I think what it also reflects is not just one mission, but it talks about a presence in space. It talks about, again, bringing humanity's curiosity and humanity's research capabilities beyond our planet.

You know, we're already on Mars, of course, with the rovers, and we're learning extraordinary things. And that's laying a foundation for a human mission to Mars in some ways. So I think it really kind of represents not just we're going to get to Mars, and we accomplished it, which, to some degree, you can say about Apollo. We had that specific goal, and we accomplished it and we sort of moved on in a lot of ways. But I do think getting to Mars probably will represent a human presence in space that—where we will finally become truly a spacefaring nation when we accomplish that goal. So I think it's reflective of Apollo, but I also think it is a beginning of a different orientation of humanity in space.

Mr. PERLMUTTER. Thank you very much.

Chairwoman JOHNSON. Thank you very much. Dr. Foster.

Mr. FOSTER. Thank you, Madam Chair.

For almost all scientists my age, you know, I grew up with the Apollo program. I remember in sometime around second or third grade we would stuff tin cans full of cotton balls soaked in rubbing alcohol that we scored from my neighbor's mother's supply of that, and we attempted to build rockets that did a pretty good job of burning down on the launchpad and not much else. You know, we didn't really understand the need for carrying oxidizer.

Later on, I built and operated Estes model rockets of the Gemini Titan, you know, mission. And by the time of the landing in 1969, I was 14, and I had spent many, many hours studying a book on looking at different mission options and calculating all the parameters for different mission options of the Apollo program. And, you know, for example, why the first stage of the Saturn booster was kerosene liquid oxygen whereas hydrogen—liquid hydrogen, liquid oxygen were the second and third stages, that sort of thing. At the time I didn't yet know calculus, but I did understand, you know, the rocket equation and Delta V and looked at all the Delta V and mission and payload requirements for all the different things that had been considered.

And even then I understood the crucial importance of what became the lunar orbit rendezvous, in making it possible to deliver on John Kennedy's promise of landing a man on the Moon within the decade.

And so today, I'd like to use my time to honor John Houbolt, a native of Joliet, Illinois, in my district, who was one of the great unsung heroes of the Apollo program. I was pleased to see, Mr. Fishman, on page 235 of your book and the pages following, you do justice to his contribution, so thank you for that.

Dr. Houbolt provided this crucial engineering concept of lunar orbit rendezvous that made the success of the Apollo program possible. Without it, the Saturn booster would have to be two times bigger or you'd need multiple of them. And it would not have been possible to meet John Kennedy's goal of landing within the decade.

John Houbolt came from humble beginnings, working 16 hours a day on his family's dairy farm in Joliet, Illinois, where he developed an early interest in aviation, building model airplanes in his free time. He graduated from Joliet Township High School and Joliet Junior College, obtained a bachelor's and master's degree from the University of Illinois in civil engineering and went on to obtain a Ph.D. and serve as an engineer at NASA Langley.

His contributions to the U.S. space program in the 1960s were vital to NASA's successful Moon landing. He's best known for his advocacy of lunar orbit rendezvous, the crucial mission decision that proved essential to carry the Apollo crew safely to the Moon and back in 1969. Dr. Houbolt, along with several of his colleagues at Langley, became convinced that this relatively obscure technique was the only feasible way to land on the Moon within the decade. And despite opposition from NASA and other leading rocket scientists at the time, Dr. Houbolt tenaciously advocated for lunar orbit rendezvous.

It was simply not possible with the engines and boosters that could plausibly be developed in the 1960s to launch a payload that would allow a manned rocket to land in its entirety on the Moon, including all the fuel necessary to get back to Earth. But as John Houbolt pointed out that if you left the fuel for the return trip in lunar orbit and rendezvoused with the command module after making the landing, then a single Saturn booster already under design at Marshall Space Flight Center could do the job. NASA Administrator George Low later said of this pivotal moment, "It's my strongly held opinion that without the lunar rendezvous mode, Apollo would not have succeeded."

And so I just wanted to say how much I appreciate, you know, seeing in your book, Mr. Fishman, you know, the proper due there.

The lunar rendezvous mode has been described by space historians as Langley's most important contribution to the Apollo program, and it's widely credited with allowing the U.S. to succeed at President Kennedy's goal.

Dr. Houbolt was often known as a voice in the wilderness or sometimes the "rendezvous man," as you point out in your book, and his persistence and the professional risk that he took, you know, ultimately were crucial to the success of the Apollo program and our victory in the space race.

He received numerous awards for his work, including NASA's Medal of Exceptional Scientific Achievement. He was elected to the National Academy of Engineering and was the first recipient of the Joliet Junior College Distinguished Alumni Award.

Dr. Houbolt retired after a distinguished career in 1985 and passed away on April 15, 2014, at the age of 95. You can Google up a floor speech I gave in his honor in the U.S. House at the time.

He and his extended family remain noted philanthropists and supporters of the community of Joliet, touching countless individuals and institutions with their generosity. His life is an example of the impact that a determined, intelligent, and passionate individual can have.

So I just want to say, Mr. Fishman, do you have anything to add to that?

Mr. FISHMAN. You've paid tribute to John Houbolt better than any of us could, I think. To me, the most important lesson there is going to the Moon has this aura of sort of completeness and seamlessness now, but it was a human endeavor. It was a workplace, almost half a million people. There were lots of real disagreements. There was real passion. And you needed individuals who had real conviction in order to get all the way. And so it wasn't just this smooth, seamless effort in which every choice was clear. It really required individuals to stand up and argue on behalf of what they believed. And John Houbolt did that in the face not just of opposition but sometimes outright contempt. And in the end NASA turned around and not only adopted his method, they said to him you were right, sir. You were arguing for the right thing all along.

Mr. FOSTER. And the argument was based on numbers and truth and scientific and engineering facts. And that's——

Mr. FISHMAN. Right. It was——

Mr. FOSTER. That was the guide star, and we're having a——

Mr. FISHMAN. Yes.

Mr. FOSTER. You know, later on, in this Committee we're having a hearing on the importance of facts and numbers and scientific truth in government, and I think we can take a lesson there, too. Thank you, and I yield back.

Chairwoman JOHNSON. Thank you very much. Now, the former Governor of Florida, the home of the Kennedy Space Center, Mr. Crist.

Mr. CRIST. Thank you, Madam Chair, and thank you for scheduling this hearing. And I especially want to thank the witnesses for being here today and taking up your valuable time to be with us and share your thoughts about this historic week that we are beginning today, you know, 50 years ago.

And, as a Floridian, you know, I can remember as a kid getting on the roof of my parents' house in St. Petersburg sort of right across the State from the Kennedy Space Center, and watching launches all the time. And it was inspirational and amazing for all of us, I think.

And so I wanted to ask each of you, what do you think was the single most important thing to come from the Apollo mission for us as a Nation?

Dr. JAKAB. Well, I think it wasn't one thing. I mean, we talked about so many different elements of the Apollo era. We've talked about the technology, we've talked about the political environment, we've talked about the need to have a purpose and commitment. We've talked about how we need to inspire ourselves as a Nation and sustain that inspiration and commitment and so forth.

So I think as we, you know, look back at Apollo this week, yes, we can point to satellite technology and we can all pull out our cell phones and say, you know, there's a link to Apollo here and so forth. But I think what we really—the larger reflection is that all of these things came together in a powerful way that have changed our world, and we did it as a society. We did it as a people. We did it as a group. And if we can somehow communicate to our citizenry today that within the group there is power and within that power is accomplishment, that's probably to my way of thinking—when I look up at the Moon and think about—and I've had the great privilege in my job to have met Neil Armstrong and John Glenn and many of the great pioneers who accomplished that goal, I can look at the Moon and I can see the accomplishment of all those people, but I can see the accomplishment of the group, and I think that's perhaps the most profound lesson.

Dr. MILLER. I tend to think about it—it's the realization we live in a three-dimensional world. I know we all believe we live in it, but really, we're sort of two-dimensional. You know, our roads are two-dimensional, our—and that sometimes our thinking can be two-dimensional in that way. And the fact that there's this third dimension and it is the—it is by far the most vast dimension and the one we know the least about I think has really just sparked a whole bunch of careers and a whole bunch of passion for the field and a whole bunch of opportunity that is there for the taking if only we'll do that, take it.

Mr. FISHMAN. I think it's worth injecting another little burst of reality. It was an incredibly unified effort and an incredibly unifying effort, but it took place in the context of the most divisive time in American culture going back to the Civil War. And so in some ways the achievement is all the more remarkable because the political and cultural context of the late 1960s was not unified at all.

And so the women weaving the circuitry for the computers, the women making spacesuits, the people building the lunar module, nobody said before they climbed into the lunar module cabin under construction which side are you on Vietnam? They—you know, this project proceeded in the midst of a lot of important national conversations that were not in fact calm or unified. So we cannot only do great things, we don't need to wait for some particular moment of unity. What we need is leadership.

I think there's a second sort of myth that it's worth puncturing, and that is Apollo is not in fact that expensive. We sort of keep hearing that it was really expensive. The budget of NASA today is 1/10 proportionally what it was then. All in, Apollo cost $19.4 billion. That's actual dollars spent in the years they were spent. You hear the $24 billion. That's inflation-adjusted to 1974, $19.4 billion in the years they were spent.

The Vietnam War had 2 years of the 10-year war, each of which cost more than $19.4 billion. There were 2 years of fighting in Vietnam, each of which cost more than the entire race to the Moon, not to mention the other 8 years of the war.

Apollo lasted from 1961 to 1972, call it $20 billion. Americans spent $40 billion buying cigarettes from 1961 to 1972. Whether it was a good use of money is a separate question, but we could certainly afford it. And so in the context of 2019, I think it's important to look at that as well and sort of say what can we afford and what will we get for it?

Mr. CRIST. Well, thank you. My time is about up, so I'll wrap up, Madam Chair. But, Mr. Fishman, I can't help but think about what you just said about, you know, Apollo occurring at one of the most divisive times in American history since the Civil War. And of course if you watch the news today, people comment much about the divisive nature of our society in America today in the same way. And so what better moment in time perhaps than for us to have the opportunity to get back to the Moon and be re-inspired and reunified.

Chairwoman JOHNSON. Thank you very much. Before bringing the hearing to a close, I want to thank all of our witnesses for testifying before the Committee today and tell you how much we appreciate you coming and sharing this history with us.

The record will remain open for 2 weeks for additional statements from Members and for any additional questions that the Committee may have of the witnesses. The witnesses are now excused, and the hearing is adjourned.

[Whereupon, at 12:22 p.m., the Committee was adjourned.]

Appendix I

ADDITIONAL MATERIAL FOR THE RECORD

Letter submitted by Representative Eddie Bernice Johnson

July 16, 2019

The Honorable Chairwoman Eddie Bernice Johnson and the Honorable Ranking Member Frank Lucas
2321 Rayburn House Office Building, 45 Independence Ave SW, Washington, DC 20515

Dear Representative Eddie Bernice Johnson and Representative Frank Lucas:

It is a real honor to have the opportunity to pay homage to Apollo 11 on its 50th anniversary. For this, I would like to share some of my own experiences with the Apollo missions, and in particular Apollo 11, and what they have meant to me.

In 1964, MIT put an ad in the paper looking for math majors to build software "to help send man to the moon". I had been working at MIT since 1959: first for Edward Lorenz (the father of chaos theory), who introduced me to computers, where I developed long-range weather prediction software; and for the SAGE system at MIT's Lincoln Labs, developing software that searched for enemy aircraft. As exciting as these projects were, the idea of working on the Apollo project was too tempting to pass up—the idea of it, itself, and the fact it had never been done before. My plans to go to graduate school and study abstract mathematics were put on hold indefinitely—60 years ago and counting!

I began by building software for the unmanned missions. Manned missions were next. I now led the team that developed the on-board flight software for both the Command Module and the Lunar Module. This would be the greatest challenge, because the software now had to be "man-rated", meaning human lives were at stake. There was no second chance. We all knew that. The software would need to be ultra-reliable, It would need to work—the first time. It would have to be able to detect anything unexpected and recover from it in real time. It would have to be perfect. Problems had to be solved never solved before.

I was always searching for new ways to prepare for the unexpected. For each problem, I thought, there had to be a way to solve this. There was. Coming up with a problem was one thing, but there needed to be a solution before the problem would be presented to the hardware and mission gurus. No one was willing to compromise the man-rated requirements, even though the solution was not without the risk of doing things never done before.

Apollo 11 was special. We had never gone to the moon before. On July 20, 1969, as Neil Armstrong and Buzz Aldrin were descending down to the lunar surface, everything was going perfectly. Walter Cronkite was reporting the mission in great detail. All of a sudden, something totally unexpected happened. Just as the astronauts were about to land on the moon, the software's Priority Displays interrupted the astronauts' normal mission displays and replaced them with priority alarm displays to warn them there was an emergency; the "never supposed to happen" alarms, in this case, 1202 and 1201, each indicating a computer overload, reminded the astronauts to place the rendezvous radar switch back in the right position and gave them a go/no-go decision—*land or not land.* With little time to spare, mission control gave the "Go" order to land, avoiding a mission abort. A few minutes later, Armstrong and Aldrin touched down on the moon. The Apollo 11 astronauts became the first humans to *walk* on the moon; and our software became the first software to *run* on the moon.

The software experience, itself, was at least as exciting as the events surrounding the mission. The flight software's error detection and recovery mechanisms had come to the rescue. This would not have been possible without the major contributions made by the other groups—MIT's hardware team and NASA's mission planning and mission control teams—to support us in making this a reality.

The flight software's error detection and recovery programs had been well prepared to warn the astronauts and at the same time go through the process of reconfiguring the mission in real time, dumping less important jobs and keeping only the most important jobs; each and every job in the software having been assigned a unique priority by the software engineers.

The story about the Apollo 11 landing was one of error detection and recovery in real time. It was about the astronauts, mission control, the software and the hardware; and how they all worked together during an emergency as an integrated system of systems. It was about creating new, man-machine and software engineering concepts to do things never done before. Apollo 11 was the very first mission in which asynchronous software worked in conjunction with the Priority Displays—allowing the software to interrupt the astronauts—the software residing in parallel with the astronauts within a distributed system of systems environment. In other words, this was the first time that the flight software communicated directly—and asynchronously—with the astronauts. Unlike a typical system where the software (or hardware) could "know" of a serious problem without the pilot's knowing it, the Priority Displays were able to determine right away if a particular alarm had occurred that fell within the category of an "emergency alarm" and they let the astronauts know about it.

As developers, we had the opportunity of a lifetime—to make every kind of error humanly possible. We evolved "software engineering" rules accordingly. *No on-board flight software errors were ever known to occur during any Apollo mission.*

With initial funding from NASA and DoD, we performed an empirical study of the Apollo effort. We asked, "what can we do better for future systems—what should we keep doing because we are doing it right?" We learned to always ask "what if?"; and to always "expect the unexpected". Most interesting was what we learned from the errors we found during pre-flight testing. Our analysis resulted in a theory based on lessons learned from Apollo and later projects, its axioms leading to a universal systems language together with its automation and preventative "development before the fact" paradigm.

One day, we realized that the root problem with traditional languages and their development environments is that they support users in "fixing wrong things up" rather than in "doing things in the right way in the first place". In contrast to the traditional paradigm with its "test to death" philosophy, with a preventative paradigm, the majority of errors are not allowed into a system, in the first place, just by the way it is defined. A radical departure from the traditional, it redefines what is possible.

Today's developers say: "software is always full of bugs, even with extensive testing. It costs too much. They say "software by its very nature is destined to have these problems". 50 years ago they said the same things. True, many issues that existed then still exist today; but, does it have to be this way? We have learned, from our own work—the reason is not the nature of software, per se; it is the paradigm used to build it—one that's been here since the beginning of time and continues in force to this day. It has been shown that these issues can be addressed; if not, eliminated altogether, with the use of the preventative paradigm. It did not disappoint when put to test. What is able to be done with what has been learned, however, depends on how open we are to change.

Whatever success I may have experienced along the way, much of it was because I was in the right place at the right time; with the right opportunities and the right people. I had the benefit of beginning with no preconceived notions. Much of the credit goes not only to those I have learned from, but also to the errors I have had the opportunity of having had some responsibility in their making; without which we would not have been able to learn the things we did. Such was the case with Apollo.

The errors showed us what to do and where to go: each holding answers to questions we had not thought of asking. They told us how to exist without them. They led us to a language with a preventative paradigm where a system's definition results in many parts of the system's own life cycle becoming no longer needed. In essence, trail blazing and taking risks in unknown territory ultimately led us to a paradigm that leads "before the fact" to the future. In 1960, John F. Kennedy said *"The American, by nature, is optimistic. He or she is experimental, an inventor, and a builder who builds best when called upon to build greatly. NASA's Apollo missions proved that this was indeed the case" And, we were there to witness it.*

Sincerely,

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