

DESTINATION MARS: PUTTING AMERICAN BOOTS ON THE SURFACE OF THE RED PLANET

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE, SCIENCE,
AND COMPETITIVENESS

OF THE

COMMITTEE ON COMMERCE,
SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

ONE HUNDRED FIFTEENTH CONGRESS

SECOND SESSION

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED FIFTEENTH CONGRESS

SECOND SESSION

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WEDNESDAY, JULY 25, 2018

U.S. SENATE,
SUBCOMMITTEE ON SPACE, SCIENCE, AND COMPETITIVENESS,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Subcommittee met, pursuant to notice, at 3:11 p.m. in room SR-253, Russell Senate Office Building, Hon. Ted Cruz, Chairman of the Subcommittee, presiding.

Present: Senators Cruz [presiding], Markey, Nelson, and Peters.

OPENING STATEMENT OF HON. TED CRUZ, U.S. SENATOR FROM TEXAS

Senator CRUZ. Good afternoon. Welcome to this hearing. Thank you to each of the witnesses for being here.

On December 14, 1972, before returning home, Apollo Astronaut Gene Cernan took the last steps on the lunar surface and stated, “As I take man’s last step from the surface, back home for some time to come, but we believe not too long into the future, I’d like to just say what I believe history will record, that America’s challenge of today has forged man’s destiny of tomorrow and as we leave the Moon at Taurus Litra, we leave as we came and, God willing, as we shall return with peace and hope for all mankind.”

These words are just as true today as they were in 1972. America’s challenge during the Apollo era has forged man’s destiny. That destiny, I believe, is to put American boots on the surface of Mars.

It has been more than four decades since Gene Cernan left the lunar surface. NASA’s once again looking to return to the Moon in the 2020s and will use it in turn as a stepping stone to reach Mars in the 2030s.

Even though we’ve been to the Moon before, our return will not be easy as a generation of engineers and scientists at NASA have since left the workforce. While the moon will provide a great testing ground in preparation for the journey to Mars, we must remain vigilant and ensure that we limit costly delays that could push a crude Mars mission in the 2030s out of reach.

Let me be clear. Mars is today the focal point of our National Space Program and if American boots are to be the first to set foot on its surface, it will define a new generation, Generation Mars.

In preparation of a crude mission to Mars, NASA has been sending scientific robotic missions to the fourth planet in our Solar System for the past four decades, yet we still have much more to discover.

Last month, NASA's Curiosity Rover discovered organic compounds which may be a sign that there was once life on Mars. While the discovery of organic compounds leaves scientists with more and more questions, it also leads us to believe that we may be on the right track.

And just today, the *Journal of Science* published a report on radar evidence of sub-glacial liquid water on Mars. Using radar profiles collected from a satellite between May 2012 and December 2015, scientists have found evidence of a 12-mile-wide reservoir of briny water beneath the South Polar Layer Deposits.

This and other exciting discoveries deserve to be built upon, explored, and studied to their full potential. That's why we're gathered here today. To build upon the framework that was established in the NASA Transition Authorization Act of 2017 and to make progress in ensuring that our Nation's exploration priorities are being met so that we can push humans further than they've ever gone before.

Somewhere in a classroom today, in Texas or Florida or Massachusetts, sits a child who may one day become the first American to reach the surface of the Red Planet. It's our responsibility to ensure that we have a national space program that can help turn that dream into a reality.

With that, I'll recognize the Ranking Member of our Subcommittee, Senator Markey.

**STATEMENT OF HON. EDWARD MARKEY,
U.S. SENATOR FROM MASSACHUSETTS**

Senator MARKEY. Thank you. By the way, there was already a schoolchild from Massachusetts, from Rindge Tech, Matt Damon. He was already the first person to step foot on——

[Laughter.]

Senator MARKEY.—the Moon.

Senator CRUZ. And one of these days, we'll bring him back.

Senator MARKEY. So we're very proud of our high school and grammar school educational process.

So next year, we celebrate the 50th Anniversary of the Apollo 11 Lunar Landing. For nearly 50 years, we have known that our sky is not a ceiling. We have known that no mission is beyond the power of American ingenuity, and we have transferred our knowledge into transforming galactic astronomy into earthly technology, building better rockets and even researching better designs for faucets and for tires.

We have set our sights further beyond the Moon and on to Mars. For nearly 50 years, NASA has stood for new adventures in space abound and in the 1960s, NASA's first successful Mars mission showed us the first up-close images of the cratered Martian surface.

Only last month, the Curiosity Rover found ancient organic molecules on the Martian surface and our next adventure will be the

launch of the Mars 2020 Rover, which will look for signs that Mars was once habitable billions of years ago.

Just today, we learned that the Italian Space Agency found a lake of liquid water beneath the Southern Polar Ice Cap of Mars. As Ray Bradbury writes in the *Martian Chronicles*, “It is good to renew one’s wonder,” said the philosopher. “Space travel has again made children of us all.”

All of these missions have not only inspired wonder and raised questions, they have also prepared us for mankind’s next great achievement in space, putting humans on the surface of Mars.

As a nation, we’ve dreamed of putting humans on Mars since the year we put boots on the moon. NASA has made great strides. The Space Launch System rocket and Orion Spacecraft are in development as we speak. Critical scientific experiments are being carried out on the International Space Station in low-Earth orbit, including technology demonstrations from one of our witnesses, Dr. Dava Newman of the Massachusetts Institute of Technology, who will testify here later.

However, NASA faces many setbacks, some self-inflicted. NASA was supposed to deliver a human exploration roadmap by December 2017, but still has not provided it to Congress.

Without this step-by-step plan, we will be flying blind as to what comes next in our quest to have humans reach the Red Planet.

This Administration also has not made its own priorities clear when it comes to human spaceflight. In December of last year, President Trump stated, “Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization followed by human missions to Mars and other destinations.”

This sounds less like a plan to go boldly where no human has gone before but, rather, a plan to return to where we have already been.

We need to help NASA lift its gaze past the Moon and understand how the work we do in space closer to Earth will serve us in our quest for Mars.

NASA and Congress will have to make tough decisions when it comes to funding. We have heard testimony in the Subcommittee that the International Space Station is a vital platform on which astronauts perform essential scientific studies, but we have to make the math add up.

How can we fund the Space Station while also funding a human spaceflight program that gets us to the Martian surface? How can we balance the push for new discoveries on Mars with the continued importance of performing science in the low-Earth and other orbits?

These are the questions we have to ask ourselves as we move forward on a NASA authorization bill that lays out a trajectory for this agency.

I know that my colleagues and I look forward to that day when we bid farewell and God speed to our best and brightest explorers and scientists as they journey to the Red Planet of our Solar System, going where none have gone before.

It has been nearly half a century since that greatest of all human achievements, Apollo 11. We must ensure that the extraordinary space race is not merely a sprint but an interplanetary marathon.

We thank all the witnesses today and I thank you, Mr. Chairman, for this very important hearing.

Senator CRUZ. Thank you, Senator Markey.

I would now recognize the Ranking Member of the Full Committee, Senator Nelson.

**STATEMENT OF HON. BILL NELSON,
U.S. SENATOR FROM FLORIDA**

Senator NELSON. I want to say that you boys are getting pretty good with your visionary rhetoric. I could close my eyes, Senator Markey, listening to that lilting Bostonian accent and I could think back to the time when it was a Bostonian that set us off on this journey and a Bostonian that allowed that journey because he had the vision to say we're going to the moon and back safely within the decade that allowed Dr. Buzz Aldrin, who is with us in the front row, along with Neil Armstrong, to set foot on that body 250,000 miles away. So, thank you for your soaring rhetoric.

To bring it right back down here, the excitement is palpable. We are about ready to start having Americans crawl into American spacecraft and lift off from the Cape and when that happens, what we're going to see is this nation suddenly gripped and captivated because we are back in space flight, even though we've been there and six humans are up there in the Space Station right now.

By the way, thank you, Mr. Chairman, for joining me and others as we are going to keep the Space Station alive instead of this nonsense that they're going to shut it down in a few years and lose that \$100 billion investment.

We've got to keep it operating safely and productively. We need to get our new crewed vehicles across the finish line, get them launched, first test flight hopefully by the end of this year, and then the first human flights early next year.

We need to finish building SLS, Orion, and the infrastructure on the Cape to launch all of the exciting new activities, and we need to keep up NASA's world-leading work on science and aeronautics, the first A in NASA.

And we need to prioritize the kinds of technology investments that will make a mission to Mars safer, more productive, and more affordable. Also, your constituent, Matt Damon, who, by the way, in the book and the movie, was propelled there by a technology that was developed by an MIT graduate, one of two astronauts that have flown the most, Dr. Franklin Chang-Diaz, who is still working on that plasma rocket.

This year's budget request from NASA proposed some new programs, including efforts to develop a range of small, medium, and larger lunar landers, and ultimately leading toward a human lunar lander. The request also included development of a human-attended Gateway to Orbit.

Now the good thing about a Gateway is lunar orbit would become what earth orbit used to be in the assembling of spacecraft and the launch point from which commercial ventures could go to the surface of the Moon. We've got to watch our expenditures for NASA

about going down to the Moon because we don't want to rob NASA's budget dedicated to the goal of getting to Mars with humans.

The Gateway was previously portrayed by NASA leadership as a test vehicle for deep space transport to take us to Mars but notably absent from this request is any mention of the Mars transport vehicle. We better watch that if we want to stay on the course for Mars.

And so, as we review these proposals, we need to think about two important points. Do these missions help us achieve our goal of getting humans to Mars, and, second, show me the money.

The Augustine Commission found NASA needed an increase of a few billion dollars a year and increases that will at least keep pace with inflation to do any sort of meaningful exploration program, and a couple of years later, the National Academies found that if we only get increases in NASA's budget equivalent to inflation, forget the scenario of going to Mars in the decade of the 2030s. It would take us until 2050. I don't think we want to wait that long because international and private partnerships, if employed smartly, could certainly help us improve the affordability of our exploration program.

And in recent years, Congress has given NASA some pretty healthy budget increases. I know we're going to continue to push for those increases, but we need a plan that keeps everyone, industry, Congress, our international partners, the men and women of NASA, all pulling in the same direction.

Our 2017 NASA Authorization Bill, Senator Cruz, required NASA to define and deliver to Congress a step-by-step plan for reaching Mars. We don't have this roadmap yet. It's 7 months overdue.

But, anyway, NASA is moving on major acquisitions, like the development of a large lunar lander. What gives? Let's see the program for going to Mars and how all of this other stuff fits in.

We need to make sure we're making smart choices. We don't have the luxury of having near five percent of the Federal budget going to NASA as it was in the time of Astronauts Armstrong and Aldrin. We need to make sure that we understand what NASA needs to do and what is being asked of them.

So thank you, Mr. Chairman, for calling this hearing.

Senator CRUZ. Thank you, Senator Nelson.

Let me thank Senator Nelson and Senator Markey, both, for your strong leadership in ensuring and continuing the bipartisan support for NASA and our space exploration mission.

I guess I have to apologize to the witnesses that apparently you've been overshadowed by a mystery witness, Matt Damon, and, you know, I would note that in his journey to Mars, Mr. Damon demonstrated the ability to grow potatoes in human excrement and I would note likewise there is no greater repository of expertise in that biofuel than the U.S. Congress.

[Laughter.]

Senator CRUZ. So with that,—

Senator MARKEY. May I just say that we are the most Irish city in the United States and we're very good at growing potatoes, something that we learned in the New World, and to Senator Nel-

son, I did not use the full accent in talking about the future and leaving behind the past. I decided to use the Mauldin version of that accent, but nonetheless the vision of President Kennedy still lives.

Senator CRUZ. With that, I am happy to introduce our distinguished witnesses today.

Our first witness is Dr. Peggy Whitson, who is a retired NASA astronaut and a biochemist. A native of Iowa, Dr. Whitson has had a career at NASA which includes becoming the first woman to serve as their Astronaut Core Chief and the first female Commander of the International Space Station.

Dr. Whitson has completed three long-duration missions to the ISS, which include 10 space walks and setting the record for the most time in space by a U.S. astronaut at 665 days.

Prior to being selected to serve as an astronaut, Dr. Whitson received her Ph.D. in Biochemistry from Rice University, my mother's alma mater, and worked as a research biochemist in the Biomedical Operations and Research Branch at NASA's Johnson Space Center.

Our second witness is Mr. Tory Bruno, who is the President and Chief Executive for United Launch Alliance, which utilizes the Atlas and Delta Rocket Families, and has achieved more than 120 consecutive launches since 2006.

In his role as CEO, Mr. Bruno serves as the principal strategic leader of the organization and oversees all business, management, and operations while managing a nationwide team of nearly 2,500 employees.

Prior to joining ULA, Mr. Bruno served as the Vice President and General Manager of Lockheed-Martin's Strategic and Missile Defense Systems.

Mr. Bruno holds a Bachelor's degree in Mechanical Engineering from the California Polytechnic State University.

Our next witness is Mr. Chris Carberry, who is the CEO and Co-Founder of Explore Mars, Inc., a nonprofit created to advance the goal of sending humans to Mars within the next two decades.

Prior to joining Explore Mars, Mr. Carberry served as the Executive Director to the Mars Society. In recent years, Mr. Carberry has led the successful International Conferences, including the ISS and Mars Conference in Washington, D.C., and Strasburg, France.

Prior to his space career, Mr. Carberry worked as an Archivist of Modern Political Papers and was a research assistant for numerous best-selling biographers.

And, finally, Dr. Dava Newman, currently serves as the Apollo Program Professor for Aeronautics and Astronautics at the Harvard-MIT Division of Health, Sciences, and Technology.

Dr. Newman's research includes advanced spacesuit design, dynamics, and control of astronaut motion, mission analysis, and engineer systems design and policy analysis.

From May 2015 to January 2017, Dr. Newman served as the Deputy Administrator of NASA. In the role as Deputy Administrator, Dr. Newman was responsible for providing overall leadership, planning, and policy direction for NASA.

Dr. Newman received her Ph.D. from MIT in Aerospace Biomedical Engineering.

And with that, Dr. Whitson, you may begin.

**STATEMENT OF DR. PEGGY WHITSON,
FORMER NASA ASTRONAUT**

Dr. WHITSON. Mr. Chairman and Members of the Committee, I'm really pleased to be here today to chat with you about America's plans for deep space exploration, including missions to Mars.

Within my 30 years of experience at NASA, I have watched our exploration goals evolve, becoming a global effort now, and advancing humanity's presence and continued exploration of space.

The future exploration plan is complex and necessarily integrated across commercial and international lines, as was recommended by some of the Committee members, and I also agree that that is as it should be.

While the idea of expanding our horizons is a simple one, the actual design solutions, the implementation of a plan, adapting when problems invariably strike, and pressing forward, in spite of obstacles is the embodiment of exploration.

Sustainability is going to be key to our success in our future exploration, so learning from each successive advancement will give us an enduring platform for growth, and although space is the goal, the benefits of the end results will be here much closer to home, spurring additional commercial activity in low-Earth orbit and expanding our knowledge and opportunities here on Earth as we search for and find those necessary and innovative solutions that we're going to need for those next exploration steps.

For example, our technologies that we've developed onboard the International Space Station on water purification and recycling, they're a critical component for our continued exploration to the Moon and Mars, but they also have huge potential here on Earth in areas where clean water is limited and now maybe in a lake, it might be handy there, too.

United States-led exploration of humans to the Moon via the Lunar Orbiting Platform Gateway will allow for sustainable exploration and scientific utilization as well as the practical testing of new partial gravity technologies and operations methods, solar electric propulsion techniques that are all critical components for our subsequent missions to Mars.

Mr. Chairman, in my 665 days in space, I've personally experienced overcoming seemingly impossible obstacles, learning resourcefulness imposed by the unique and harsh environment of space, and I've seen some of the best of what human beings have to offer, and been lucky enough to be a part of a world community that has striven to each new level of competence, including the advancement of commercial capabilities.

So I recommend we take the lessons that we've learned on the International Space Station, understanding that it is a microcosm of what we need to happen on a much larger scale for our future exploration activities.

I believe that developing a flexible deep space infrastructure to support a steady cadence of increasingly complex missions will strengthen American leadership in our quest to go where no person has gone before.

By leveraging commercial and international collaborations, we will ensure that the best minds in the world are working toward our exploration objectives and with NASA's leadership, a logical approach to expand our reach and sustainability of human space exploration will continue, building on the station and increasing with our capabilities in our new Heavy Lift SLS and Crew Orion Capsule and the Exploration Ground Systems.

These strategies hold the highest likelihood of success and promise to extend technical and scientific benefits to all of humankind.

On a personal note, thinking back to on my rural Iowa farm beginnings and seemingly impossible dreams, I want our exploration to fire the imaginations of all people. There really are no boundaries.

So I'd be pleased to respond to any questions from you, Mr. Chairman, and the Committee.

[The prepared statement of Dr. Whitson follows:]

PREPARED STATEMENT OF DR. PEGGY WHITSON, FORMER NASA ASTRONAUT

Introduction

Mr. Chairman and Members of the Committee, I am pleased to have this opportunity to discuss America's plans for deep space exploration, including sending human missions to Mars. Within my 30 years of experience at NASA, I have watched our exploration goals evolve, becoming now a global effort to advance humanity's presence and continued exploration of space. The future exploration plan is complex and necessarily integrated across commercial and international lines. As it should be. While the idea of expanding our horizons is simple, the actual design solutions and the implementation of a plan, adapting when problems invariably strike, and pressing forward in spite of obstacles is the embodiment of exploration.

Sustainability will be a key in the success of our future exploration as we expand our presence across the solar system. Learning and building from each successive advancement will give us an enduring platform for growth. And though space is the goal, the benefits of the end results will be closer to home, spurring additional commercial activity in low-Earth orbit [LEO] and expanding our knowledge and opportunities here on Earth as we search for and find those necessary innovative solutions. For example, our technologies developed for water purification and recycling on the International Space Station [ISS], a critical component for continued exploration to the Moon and Mars, also have applications on Earth in areas where clean water is limited. A United States led expansion of humans to the Moon via the Gateway will allow for sustainable exploration and scientific utilization, as well as the practical testing of new partial gravity technologies and operations methods that are critical for the subsequent missions to Mars.

NASA's Exploration Campaign addresses the necessity of developing a sustainable approach, pursuing a new lunar exploration program by employing expertise and resources across the Agency and commercial and international partners in support of: a science and technology initiative; a small commercial lander initiative; a development activity for commercial mid-to-large landers to address both science and human exploration objectives; and Gateway. The effort is built to enable early successes, with seamless collaborations.

International Space Station

With three trips to the ISS over the last 16 years, I can personally vouch for its value in the evolution of our space exploration. International and commercial relationships have been built and forged and continue to expand in ever-changing roles. These partnerships will be critical to future successes in space, as we approach even more difficult problems, further from our home world. Also, on ISS we have incorporated the hard-earned lessons of building, repairing and living in the most complex engineering achievement ever constructed in the vacuum of space. All of these lessons will apply during the establishment of our presence in deep space and on the lunar and Mars surfaces. The ISS also serves as an invaluable platform for testing, redesigning and re-testing technologies that will make our next steps away from the planet sustainable.

For the human part of the equation, we have conducted literally hundreds of experiments during our 18-year presence on board the ISS, specifically expanding our

knowledge about the effects of living in space and developing new protocols and mitigations to reduce our risks of being there. Studies ranging from bone loss and exercise mitigations to spaceflight neuro-ocular system changes, nutrition requirements, host-microorganism interactions, and immune response have been completed or are on-going now. Knowledge gained is being incorporated into future vehicle designs and operations protocols that will enable our continued human presence beyond Earth.

As a scientist myself, I am truly excited about the whole range of research that we are able to conduct on board station, including research in engineering and physical sciences, biology, the Earth, and the universe. Soybeans to superconductor crystals, cardiac stem cells and antibody-conjugated cancer drug therapies, and fuel combustion experiments is just a tiny list of some of the space research in which I personally participated. Under the auspices of the ISS National Laboratory, managed by the Center for the Advancement of Science In Space (CASIS), NASA and CASIS continue to expand research on the ISS sponsored by pharmaceutical, technology, consumer product, and other industries, as well as by other Government agencies, such as the National Institutes of Health and the National Science Foundation. I anticipate that this research will grow into a commercial industry as more and more studies demonstrate the value of the ISS as a National Laboratory.

Systems for Exploration

New deep space systems, including the heavy-lift Space Launch System (SLS), Orion crew vehicle, the Exploration Ground Systems (EGS) that support them, commercial launch vehicles, lunar landers, and new deep space habitation capabilities, are being developed by NASA through public-private and international partnerships. Missions planned on SLS in the 2020s will establish the capability to operate safely and productively in deep space.

A key component of the sustainability and flexibility of the plan will include the presence of a Gateway. In addition to a U.S. strategic presence in lunar space, the Gateway will be a place to live, learn and work around the Moon and will provide opportunities to support missions to the surface. Leveraging the knowledge gained in exploring the Moon and utilizing its situ resources will then directly apply toward human missions to Mars. Testing and refining in-space power and propulsion and deep space habitation will also be critical objectives to test and refine for the success of a human presence on Mars.

An Integrated Effort

NASA's Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) lander launched in May, 2018 and will land on Mars in November—joining a series of NASA rovers, landers, and orbiters already at the Red Planet. InSight's advanced payload will provide unique information on the interior structure of Mars, providing glimpses into the processes that shaped the rocky planets of the inner solar system. The future Mars 2020 rover and planning for a potential Mars Sample Return mission, incorporating commercial and international partnerships, will also provide essential data for human presence in the future.

Lunar Activities and Beyond

As part of the NASA's overall strategy to conduct deep space exploration, the Agency is supporting the development of commercial lunar exploration. A new cross-Agency campaign will combine science and exploration objectives in Advanced Cislunar and Surface Capabilities. One specific example of this approach is the Lunar Cargo Transportation and Landing by Soft Touchdown (CATALYST) initiative, which encourages the development of U.S. private-sector robotic lunar landers capable of successfully delivering payloads to the lunar surface using U.S. commercial launch capabilities. As part of the Exploration Campaign, NASA will initiate a series of robotic lunar missions in partnership with industry as early as 2019, eventually leading to a continual human presence on and around the Moon.

NASA also is at work on the second phase of the Next Space Technologies for Exploration Partnerships (NextSTEP), an effort to stimulate deep-space capability development across the aerospace industry. Through these initial public-private partnerships, NextSTEP will provide advanced concept studies, technology development projects, and significant measurements in key areas, including habitat concepts, environmental control and life support systems, advanced in-space propulsion, and small spacecraft to conduct missions related to strategic knowledge gaps. NASA is already integrating ground testing of habitation capabilities developed by the NextSTEP partners.

Conclusion

In my 665 days in space, I have personally experienced overcoming seemingly impossible obstacles, learning resourcefulness imposed by the unique and harsh environment of space. I have seen some of the best of what human beings have to offer. And been lucky enough to have participated as a member of our world community in striving for each new level of competence, including the advancement of commercial capabilities. I recommend that we take these lessons from Space Station, understanding that it is a microcosm of what will need to happen on much larger scale in our future exploration.

I believe that developing a flexible deep space infrastructure to support a steady cadence of increasingly complex missions will strengthen American leadership in a quest to go where no person has gone before. By leveraging commercial partnerships and international collaborations, we will ensure that the best minds in the universe are working toward our exploration objectives. With NASA's leadership, a logical approach to expand the distance and sustainability of human space exploration will continue, building on the on the ISS, and increasing capabilities with SLS, Orion, and EGS programs. These strategies hold the highest likelihood of success and promise to extend technical and scientific benefits to all of humankind.

Mr. Chairman, I would be pleased to respond to your questions and those of other Members of the Committee.

Senator CRUZ. Thank you, Dr. Whitson.
Mr. Bruno.

STATEMENT OF SALVATORE T. "TORY" BRUNO, PRESIDENT AND CHIEF EXECUTIVE OFFICER, UNITED LAUNCH ALLIANCE, LLC

Mr. BRUNO. Thank you. Chairman Cruz, Ranking Member Markey, Ranking Member Nelson, and members of the Subcommittee, thank you for the opportunity to appear today on a subject of profound importance to our Nation and the world, Putting American Boots on Mars.

I am privileged to represent the talented team at ULA who have joined NASA in exploring missions that lay the foundation for future landings by Americans on the Red Planet.

ULA is proud to be playing its part in extending the presence of humanity to Mars. Since the company's formation in 2006, ULA has successfully launched every United States mission to the Red Planet. Our rockets have gone to Mars 18 times.

ULA's Atlas V and Delta rockets have an unmatched record of a hundred percent launch success. Our rockets have launched missions to every planet in our Solar System and beyond.

In May, we launched the Mars Insight Lander, the first mission to Mars from California. In a few weeks, ULA will launch the Parker Solar Probe, the mission that will study the sun and unlock new understanding of our nearest star and its impact on our planet and the environment between here and Mars.

Clearly, Mars exploration is a vast undertaking, requiring a space industrial base of enormous breadth and depth, and ULA is critical to stabilizing that workforce.

Our company is comprised of employees at facilities in Denver, Pueblo, Decatur, Harlingen, Cape Canaveral, and Vandenberg. ULA also partners with more than 2,700 suppliers from across the country. By working with large and small suppliers, ULA plays a critical role in ensuring a stable space industrial base.

ULA recently entered into a long-term strategic partnership with AeroGen Rocketdine, selecting the flight-proven RL10 engine to power our Vulcan Centaur Upper Stage.

We have also entered into strategic partnerships with several other companies, such as L3 for avionics, and SpinCraft for fuel tank domes. All of these companies and many others supply critical components to NASA's Space Launch System, which will be the world's most powerful rocket, providing super-heavy lift for the Orion Capsule in human missions to Mars and other deep space destinations.

With ULA's core customer, these supplier companies are able to provide components to NASA and their SLS and Orion partners more affordably and demonstrate reliability in their systems with dozens of flights aboard Atlas, Delta, and soon Vulcan Centaur.

The nation's launch industrial base is critical to America's status as the premier spacefaring nation as well as to our national security and economic well-being.

With domestic and foreign competition on the rise and a launch forecast that may be flat or even declining, it is crucial Congress take steps in any space legislation to stabilize our competitive industrial base and prevent U.S. taxpayer-funded payloads from being sent overseas to be launched on foreign vehicles from foreign launch pads.

NASA must lead humanity's return to the Moon and travel to Mars and the SLS and Orion are going to get us there. We appreciate the strength and enduring nature of congressional support for these programs.

I would also like to applaud the current Administration's emphasis on returning astronauts to the Moon. Together, Congress, the Administration, and industry can chart a path forward that uses the lunar vicinity as a testbed and jumping-off point to Mars. That is where ULA will play a key role, providing cargo and scientific transportation services for commercial activities in lunar space to complement the core human spaceflight and large payloads provided by SLS and Orion.

At ULA, we have already taken the first steps in achieving this goal. ULA's Lunar 1000 Roadmap envisions self-sustaining community of a thousand people supported by some 200 companies in the space between Earth and the Moon. Developing the valuable resources that are abundant on near-earth asteroids and the lunar surface will provide a foundation for this new econosphere.

The ingenuity of America's private sector, together with NASA, will be required to extend human presence beyond Earth.

Thank you again for inviting me to be here before you today. I look forward to your questions.

[The prepared statement of Mr. Bruno follows:]

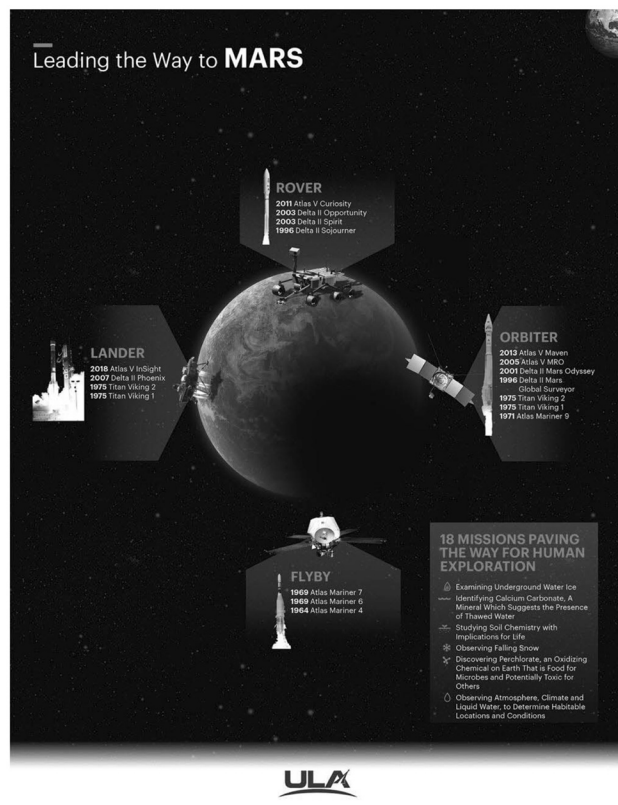
PREPARED STATEMENT OF SALVATORE T. "TORY" BRUNO, PRESIDENT AND CHIEF
EXECUTIVE OFFICER, UNITED LAUNCH ALLIANCE, LLC

Chairman Cruz, Chairman Thune, Ranking Member Markey, Ranking Member Nelson, and Members of the Subcommittee—thank you for the opportunity to appear today on a subject of profound importance to our Nation and the world—putting American boots on Mars. I am privileged to represent the talented team of ULA women and men who have joined NASA in exploring missions that lay the foundation for future landings by Americans on the Red Planet.

The grand vision for human exploration of Mars comes naturally to our great nation, with its inspirational history of pioneering. The capability to bring that vision to fruition lies in the scientific and technical prowess and industrial might of America.

ULA is proud to be playing its part in extending the presence of humanity to Mars. Since the company's formation in 2006, ULA has successfully launched every United States mission to the Red Planet. ULA's Atlas V and Delta rockets, with an unmatched record of 100 percent launch success in 128 national security, civil and commercial space missions, have launched missions to each of the planets in our solar system. All these missions have provided inestimable scientific value to the world. In just a few weeks, ULA will launch the Parker Solar Probe, a mission which will study the Sun and unlock new understanding of our nearest star and its impact to our planet and space environment. Our next generation Vulcan Centaur rocket, currently in development, will continue to provide reliable access to Mars for scientific missions while lowering launch costs.

I will briefly review our past and planned Mars exploration launches. On November 26, 2011, we launched the Mars Science Laboratory, the rover, "Curiosity," on an Atlas V 541—a mission that analyzed Martian soil searching for water. On November 18, 2013, we launched the Mars Atmospheric and Volatile Evolution (MAVEN) spacecraft, and this year on May 5, we launched the Mars Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) lander. Both of these missions launched on Atlas V 401 launch vehicles, and InSight marked the first time a mission to Mars launched from the west coast. Today, we are preparing for our launch of Mars 2020—the most ambitious of all the missions to the Red Planet. Among this mission's objectives are gathering knowledge and demonstrating technologies that address the challenges of human expeditions to Mars. Our Atlas, Delta, and heritage rockets have successfully launched 18 missions to Mars. We have the talented workforce with proven knowledge and ability to successfully accomplish missions to Mars and beyond.



Clearly, Mars exploration is a vast undertaking that requires a space industrial base of enormous breadth and depth, and ULA is critical to stabilizing that workforce. Our company is comprised of employees at facilities in Denver, Pueblo, Deca-

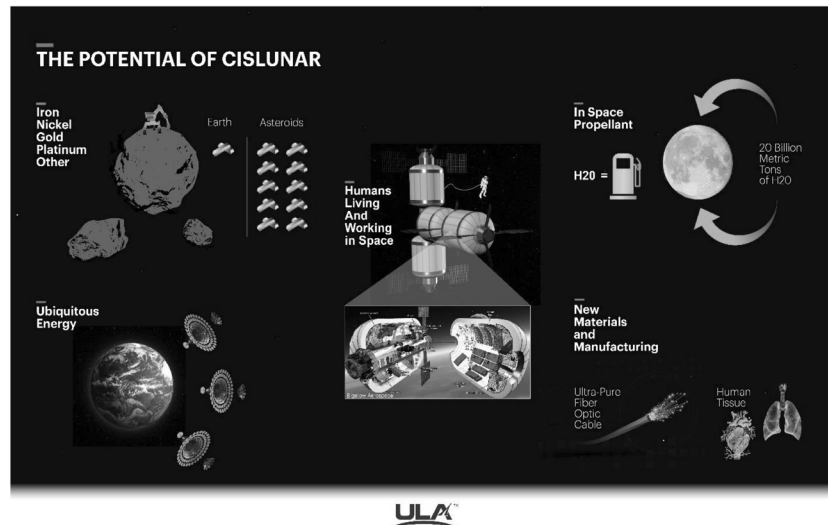
tur, and Harlingen where we conduct sophisticated launch vehicle engineering, testing, manufacturing, assembly, and integration operations—and at Cape Canaveral and Vandenberg, where we perform complex launch operations.

ULA also partners with more than 2,700 suppliers across the country, in nearly every state. By working with large and small suppliers across the country, ULA plays a critical role to ensuring a stable space industrial base. ULA recently entered into a long-term strategic partnership with Aerojet Rocketdyne, selecting the flight proven RL-10 engine to power our Vulcan Centaur upper stage. We have also entered into strategic partnerships with several other companies throughout the country such as L3 for avionics and Spincraft for spinformed fuel tank domes.

All of these companies—and many others—supply similar critical components to NASA's Space Launch System (SLS), which will be the world's most powerful rocket providing super heavy lift for the Orion capsule in human missions to Mars and other deep space destinations. With ULA as a core customer, these supplier companies are able to supply these components to NASA and their SLS and Orion industry partners more affordably, and are able to demonstrate reliability in their systems with dozens of flights aboard Atlas, Delta, and soon Vulcan Centaur.

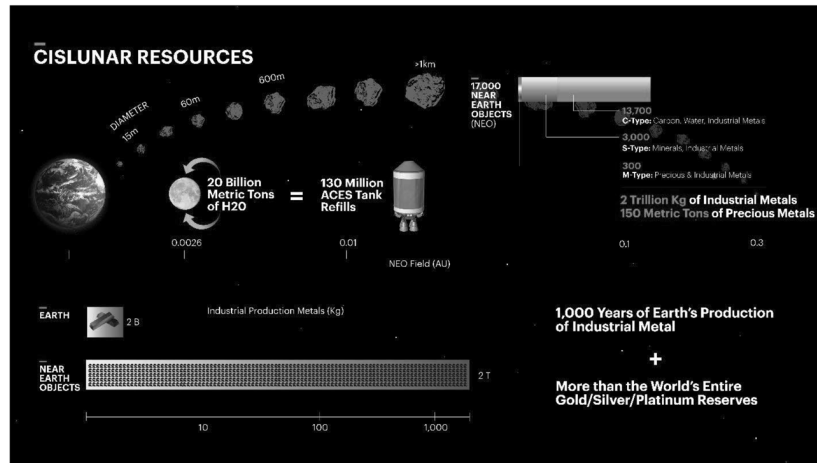
ULA has also supported NASA's flagship exploration programs by supplying the Interim Cryogenic Propulsion Stage (ICPS) for EM-1 and two additional flights. To that end, I commend Congress for funding the development of a second mobile launch platform. Allowing SLS flexibility is crucial to the Nation's success in exploring the cosmos. Additionally, ULA launched the test flight of the Orion crew capsule aboard our Delta IV Heavy (EFT-1), which provided essential data to prepare Orion crew for deep space missions.

NASA must lead humanity to return to the Moon and travel to Mars, and SLS and Orion are going to get us there. We appreciate the strength and enduring nature of Congressional support for those programs. I would also like to applaud the current Administration's emphasis on returning astronauts to the Moon. Together, Congress, the Administration, and industry can chart a path forward that uses the lunar vicinity as a test bed and jumping off point for Mars. That is where I believe ULA will play a key role: providing cargo and scientific transportation services for commercial activities in CisLunar space to complement the core human spaceflight and large payloads provided by SLS and Orion, while also allowing NASA to focus on pressing forward into deep space.



At ULA, we have already taken the first steps in achieving this goal. ULA's CisLunar 1000 roadmap envisions a commercially established, self-sustaining community of around 1,000 people supported by some 200 companies in the space between Earth and the Moon. Bigelow Aerospace, a company that is preparing to provide a space habitat for nearly 20 people to live and work in CisLunar space during the first phase of the project, has already selected ULA's Vulcan Centaur rocket to launch their B330 space habitat. Additionally, Astrobotic, a commercial lunar logistics company in Pittsburgh, has chosen to fly their Peregrine lander on ULA's

flight proven Atlas V. This will mark the first launch of a commercial lunar lander to the lunar surface from the United States. America's leaders understand the indispensable scientific and exploratory roles played by human activities in Low Earth Orbit (LEO) and CisLunar space. Our leaders also understand the vast economic opportunities we can achieve there. Developing the valuable resources that are abundant on near earth asteroids and the lunar surface will provide a financial foundation for the new "Econosphere."



Acts of Congress and presidential directives reflect the high priority that the United States Government has long placed on human space exploration. With this continuing commitment, Americans will surely land on Mars as they landed on the Moon.

The ingenuity, capabilities, and resources of America's private sector, as well as those of NASA, will be required to achieve the goal of extending human presence from LEO, to CisLunar space, to Mars and beyond. I am confident that, together, Americans are more than equal to the task.

Thank you again for inviting me to be here before you today. I look forward to your questions.

Senator CRUZ. Thank you, Mr. Bruno.
Mr. Carberry.

**STATEMENT OF CHRIS CARBERRY, CHIEF EXECUTIVE
OFFICER AND CO-FOUNDER, EXPLORE MARS, INC.**

Mr. CARBERRY. Thank you, Chairman Cruz, Ranking Member Nelson, and the Subcommittee, for the opportunity to testify at today's hearing.

I am honored to be here to discuss how the United States should lead humanity's efforts to land humans on Mars.

Next July, we're going to celebrate the 50th Anniversary of the Apollo Moon Landings. Today, we are in an exciting watershed moment, well positioned to continue where the Apollo Program left off, and poised to land Americans on the surface of Mars in the 2030s.

To further this goal, teams of scientists and engineers have participated in a series of workshops to develop scenarios for achievable Mars missions. These workshops, known as the Achieving Mars Workshops, are organized by Explore Mars in partnership with the American Astronautical Society.

These Mars scenarios have four essential characteristics. One, they're affordable. Two, they're achievable without technological

miracles. Three, they're sustainable in coordination with our partners. Four, they achieve major and longstanding scientific goals.

The most recent workshop was largely motivated by the passage of the NASA Transition Authorization Act of 2017, which states that NASA should take steps to "leading to human habitation on the surface of Mars." The Act goes on to say that NASA should contract outside organizations to "study the feasibility of the launch of a human spaceflight mission to Mars in 2033."

If this deadline is to be achieved, we can't allow ourselves to postpone critical decisions. Otherwise, we will have little hope of seeing American boots on the ground in the 2030s.

Fortunately, numerous feasible concepts to land humans on Mars were proposed by NASA, industry, and commercial players, and other stakeholders, and our workshops revealed significant commonalities among most of these scenarios.

We've outlined three architectures that span the range of likely options for human missions to Mars. The first scenario involves sortie-like missions with a two-week stay on the Martian surface and is analogous to the Apollo Program.

The second concept is a semi-permanent base or field camp with a year-and-a-half stay on the Martian surface and is analogous to early Antarctic exploration.

The third concept is sustained permanent habitation analogous to current Antarctic exploration, but with setting the stage for potential settlements and the full report for that workshop will be available in the next two weeks.

These workshops also found that any plan to send humans to Mars should acknowledge that science precursor missions in the 2020s are essential to human exploration in the 2030s.

The Mars 2020 Rover is the last robotic mission the United States currently has funded. This must not be the end of our Mars Robotic Program. We need new reconnaissance capabilities as well as deep space communications and if we plan to do a sample return mission, let's consider a heavy sample return mission that not only can bring back a significant number or amount of Mars samples, but can also be an intermediate test for entry, descent, and landing capabilities and other key technologies.

Also, precursors to the Moon should be designed and executed in a manner that will have a clear path to Mars and stimulate commercial and international participation, and as plans for the Moon and Mars proceed, experts should determine which capabilities are vital for both the Moon and Mars.

The United States is well positioned to move ahead now. NASA and its industry partners are developing launch and crew capabilities well beyond existing systems and commercial entities are advancing impressive technologies.

There's also strong support for human spaceflight, particularly Mars, amongst the public. This strength and this support becomes clearer when the public is given precise information.

For example, as shown in the 2013 Mars Generation Poll, when informed that NASA accounts for less than one-half of 1 percent of the Federal budget, the public tends to overwhelmingly support ambitious plans for space exploration.

So with bipartisan support in Congress, with unwavering public support, and, you know, clear support from the current and past Administrations, many of us wonder why our Nation seems unable to commit decision to finally enable human missions to Mars.

We don't want to squander this broad support and in 20 years find ourselves looking back to realize we were unable to return to the surface of the Moon or send humans to Mars.

Mr. Chairman and Members of the Committee, I'd like to thank you for taking the time to hold this hearing.

I conclude by saying that while we should never be reckless with the lives of our astronauts, we need to take calculated risks and be bold, as we were in the 1960s, to achieve something truly extraordinary for the United States and the world. We are well past due for the next giant leap.

Thank you.

[The prepared statement of Mr. Carberry follows:]

PREPARED STATEMENT OF CHRIS CARBERRY, CHIEF EXECUTIVE OFFICER,
EXPLORE MARS, INC.

Thank you, Chairman Cruz, Ranking Member Markey, and the other members of the Subcommittee on Space, Science, and Competitiveness, for your gracious invitation to testify at today's hearing. I am honored to be here to discuss how the United States should lead humanity's efforts to land humans on the surface of Mars by 2033.

Next July we will all be celebrating the 50th anniversary of the historic Apollo 11 Moon landing. Today the United States and our commercial and international partners are at a new and exciting watershed moment in human space exploration, and we are well-positioned to continue where the Apollo Program left off. With new launch capabilities coming online and with the continued support of Congress, the Executive Branch, and the American public, we are now poised to send crews even further into deep space with Americans landing on the surface of Mars in the 2030s.

To further this goal, teams of scientists and engineers from industry, NASA, and academia have come together as a community in a series of recent workshops, and have been developing scenarios for achievable missions to Mars. These workshops, known as the *Achieving Mars Workshops* (<https://www.exploremars.org/affording-mars>), are organized by Explore Mars, Inc., the organization that I am privileged to serve as CEO, in partnership with the American Astronautical Society, and sponsored by major aerospace companies. The scenarios for achievable Mars missions developed by these workshops have four essential characteristics:

1. They are affordable,
2. They are achievable *without* technological miracles,
3. They are sustainable in coordination with our international partners, and,
4. They achieve major and long-standing scientific goals.

Our recent workshops have been motivated to a large extent by the long-standing support of our Nation's space program by the United States Congress, including most recently with the passage of the *NASA Transition Authorization Act of 2017*, which states in part that "NASA shall take all necessary steps, . . . to ensure that activities in NASA's human exploration program balance how those activities might also help meet the requirements of future exploration and utilization activities leading to human habitation on the surface of Mars." That Act goes on to say, "NASA shall contract . . . to study the feasibility of the launch of a human space flight mission to Mars in 2033."

If this deadline is to be achieved, however, we can not allow ourselves to postpone critical decisions about specific mission architectures. Many such decisions need to be made in the very near term, otherwise there will be little hope of actually seeing American boots on the surface of Mars in the early to mid-2030s. Fortunately, we do not need to start from scratch. Over the past several years, numerous realistic and efficient concepts to land humans on Mars have been proposed by NASA, industry/commercial stakeholders, and others, and our workshops and the community that they represent have built on and refined those concepts to the point where we as a nation are ready and should be willing to act.

These workshops have revealed the high degree of commonality of the critical elements of a Mars program that exists among different scenarios for exploration of the Red Planet. There are, of course, additional key technologies and plans that must be developed in order to achieve the goal of human missions to Mars. However, the United States overcame a multitude of such challenges in order to land humans on the Moon in the 1960s, and to build an International Space Station in the decades that followed, and America can overcome whatever challenges lie ahead in order to land humans on Mars in the 2030s.

For many years, the space community has been unable to achieve consensus regarding the scope and long-term goals of initial missions to Mars. However, our most recent workshop—the 5th in the series—was specifically addressed to that situation. Workshop participants outlined three architectures that span the range of likely options for human missions to Mars, with each of these missions leading eventually to crews that would be away from Earth for roughly 1,000 days:

1. The first scenario involves “sortie-like” missions, with a two-week stay on the surface, analogous to the Apollo Program.
2. The second concept is a semi-permanent base or “field camp” on the surface, with a stay of a year and a half, and is analogous to early Antarctic exploration.
3. The third concept is a sustained, permanent habitation analogous to current Antarctic exploration, setting the stage for potential settlements.

Our series of workshops have also found that in order to succeed, any plan to send humans to Mars must encompass, in the decision-making process by NASA, policy-makers, and our partners, the following:

1. Science precursor missions in the 2020s are critical for human exploration in the 2030s. The 2020 Rover is the last robotic mission to Mars that the United States has funded. This rover *must not* be the end of our robotic missions. In advance of humans to Mars, we will need new reconnaissance capabilities around Mars, and more robust deep-space communication. If we achieve a sample return mission, which is considered a top priority, we should consider a “heavy” sample return mission that not only collects a significant amount of Martian samples, but can also provide an intermediate test for Entry, Descent, and Landing capabilities as well as employ robust experiments for in-situ resource utilization and other essential technologies needed for a sustainable human presence on Mars.
2. Lunar operations should be planned with Mars as the ultimate goal: Missions to the vicinity of the Moon should be designed and executed in a manner that will create a clear path to Mars and stimulate commercial and international participation.
3. Common “Long-Pole” Capabilities: During the 4th Achieving Mars Workshop in 2016, over a dozen “long-poles”—that is, capabilities that need to be developed and such work needs to begin immediately to accomplish humans Mars landings in the 2030s—were identified and designated. As plans for the Moon and Mars proceed, experts should determine which ‘long-poles’ are vital for both the Moon and Mars.
4. Integration is essential: Missions should be designed and conducted with unprecedented coordination among the directorates of NASA, industrial/commercial entities, and our international partners, the latter of which look to us to lead these efforts.

Regardless of which approach is chosen, and that choice must be made soon, the United States is well-positioned to move ahead now. As we all know, NASA and its industry partners are developing launch and crew capabilities well beyond any existing or previous systems, commercial entities are also advancing impressive technologies, and there is unprecedented international interest and activity in space exploration.

In addition, and also importantly, there remains strong public support for human space exploration—particularly Mars. The nature and extent of this support becomes even clearer when the public is given precise information. For example, as evidenced by the findings of the 2013 *Mars Generation National Opinion Poll* (<https://www.exploremars.org/wp-content/uploads/2013/03/Mars-Generation-Survey-full-report-March-7-2013.pdf>), when informed that NASA accounts for less than half of one percent of the Federal budget, the public tends to overwhelmingly support ambitious plans for space exploration.

The entertainment industry—whose profits are based on understanding the appetites and passions of the public—understands this national Mars enthusiasm ex-

ceedingly well. As highlighted in the 2018 *Humans to Mars Report* (<https://www.exploremars.org/the-humans-to-mars-report>), there are innumerable television and film projects underway depicting Mars exploration and settlement. While policy should certainly not be decided based solely on the current Hollywood movie trend, the continuing profitability of Mars related film projects is clear evidence of the sustained enthusiasm that the public has for Mars exploration.

With this overwhelming bi-partisan support in Congress, clear support from the current and previous administrations, and unwavering public support, many of us in the space community wonder why our Nation seems unable to commit to the decisions that will finally enable human missions to Mars. As this Committee well knows, many larger federally funded projects—projects with far less broad-based support—have been able to move forward with fewer delays, despite far less unity in Congress and among American voters.

Once again, definitive decisions are needed soon. We do not want to squander the support we now have and in twenty years in the future find ourselves looking back to realize that we were unable to return to the surface the Moon or send humanity to Mars in spite of the broad support for such missions.

Mr. Chairman and Members of the Committee, my organization, Explore Mars, Inc., and I, would like to thank you for taking the time to hold this important hearing. I would like to conclude by saying that while we should never be reckless with the lives of our astronauts, we need to take calculated risks and be bold, once again, as we were in the '60s, in order to achieve something truly extraordinary for the United States and the world. We are well past due for "the next giant leap. . ."

Senator CRUZ. Thank you, Mr. Carberry.
Dr. Newman.

**STATEMENT OF DR. DAVA J. NEWMAN, APOLLO PROGRAM
PROFESSOR OF ASTRONAUTICS—MASSACHUSETTS
INSTITUTE OF TECHNOLOGY; HEALTH, SCIENCES,
AND TECHNOLOGY—HARVARD-MIT HST; FORMER NASA
DEPUTY ADMINISTRATOR**

Dr. NEWMAN. Thank you. Chairman Cruz, Senators Nelson and Markey, Peters and Sullivan, it's my great honor to be here with you today.

Putting humans on Mars has been my lifelong passion and my entire research career, so I'm very delighted to talk to you, and I was honored to serve as NASA's Deputy Administrator previously.

In the past 40 years, we've learned an impressive amount about our sister planet Mars. Thanks to NASA's scientific robotic missions from Viking through Curiosity, we have more information on Mars than any other planet, excluding our own.

These missions have brought back amazing images, majestic alien landscapes. As mentioned today, the new discovery today, every day, I get to read this stuff, you know, a lake underneath the surface of Mars and previously the organic molecules. So it just keeps getting better all the time every day.

So really what we're here to talk about then is priorities and investments. Scientific spacecraft and rovers, they're going to continue to make great discoveries and answer the three fundamental questions of all of exploration.

Are we alone? Are there other habitable planets? What about life? The evidence is mounting in other planets.

So landing that first mission to Mars, that human mission, the women and men, we're going to surpass 50 years of our rovers. I love our rovers. They're great. But we've only gone 75 kilometers. So when we get those first boots on Mars, the first mission, we're going to surpass the last 50 years. That's how exciting it is to me to get humans to Mars and for discovery and scientific purposes.

Nothing inspires the Nation, our future generations, my students, and our students—I call them the Mars Generation—more than human spaceflight.

Putting boots on Mars has been my dream for as long as I can remember, and I was inspired by Apollo 11 because, Buzz, thank you, inspired a young girl from Montana to think everything's possible. You know, we don't have limits if we really put our minds to it, but dreams and willpower, they're not sufficient.

We already have some of the brightest scientists, engineers, and technologists putting our inventiveness and persistence to the boots on Mars journey. We've had great bipartisan support from congressional leadership, thank you, and across Administrations.

We need to build on those foundations with a clear strategy and commitments for significant long-term funding. Prioritizing on NASA's many important missions is never easy and in Congress, you have hard decisions to make.

We spent \$4 billion annually for our low-Earth orbit missions where we do really important work. I was able to fly technology demonstrators in 2015 and 2017 on suits for astronauts, but from an exploration point of view and a desire to push humanity beyond what we even think is possible, we've been stuck in low-Earth orbit for too long. We need to rethink the funding portfolio and timely investments to succeed in getting to the Moon and onward to Mars.

Strategically, getting to Mars is figuring out the optimal roles for NASA, private/commercial space ventures, and our international partners. Within NASA, we need to better integrate science, space technology, and human exploration portfolios.

I recommend a synergistic Mars program office across all three with the necessary budget.

My view of the best pathway to Mars breaks the strategy into three phases. Currently, Phase 1 on International Space Station, Phase 2 getting back to the Moon briefly, demonstrate that technologies that we need to sustain our astronauts beyond lower earth orbit; namely, they've been talked about a little bit before, heavy-lift launch capability, our solar electric propulsion, surface habitats, our life support systems and mobility systems.

So, soon we'll fly to Earth-Moon orbit and land on the Moon. We need to evaluate the feasibility, cost, schedule, and investment portfolio and then make the decision to stay the course, no dead-end elements.

Phase 3 is self-sufficient travel to Mars. Explorers will be months away from home, completely autonomous, no instant communications with Earth. Mars is hard and it's really far away.

So we'll rely on our technology investments of the 2020s in our advanced propulsion, in our smart habitats, in our advanced human machine autonomy and novel radiation protection. All of those investments now and in the 2020s will pay off to get humans to Mars.

It's going to be a completely self-supporting journey to realize just seamless interoperability between our humans and our machines. It's both. It's always humans and our machines to make the big scientific breakthroughs.

It'll take a focused strategy and technology development to implement Phase 2, getting back to the Moon, and shortly thereafter Phase 3 to assure that U.S. will lead human Mars exploration.

I might say myself and my students are working on some of these challenges. We investigate astronaut performance and reduced gravity and design suits and engineer solutions to keep them safe and healthy.

There are also Earth applications for everything we do. Specifically in my case, to help humans walk, think about how we can help with cerebral palsy, all those dual-use technology investments here on Earth.

So those investments on universities, you know, they're very low-technology readiness levels. So that's why it's crucial that we integrate science and space technology as central parts of the NASA Mars Strategy.

Increased the funding, keep it stable, develop a NASA portfolio that greatly furthers synergies among science, technology, and human exploration. It's a comprehensive phased plan. With the right leadership and coalition, it will send us beyond low-Earth orbit to the Moon and to Mars, put humans on Mars in the 2030s.

Thank you very much.

[The prepared statement of Dr. Newman follows:]

PREPARED STATEMENT OF DR. DAVA J. NEWMAN, APOLLO PROGRAM PROFESSOR OF ASTRONAUTICS—MASSACHUSETTS INSTITUTE OF TECHNOLOGY; HEALTH, SCIENCES AND TECHNOLOGY—HARVARD-MIT HST; FORMER NASA DEPUTY ADMINISTRATOR

Thank you, Chairman Cruz, Senators Nelson and Markey, and all the members of the space subcommittee and full committee for the opportunity to testify today. Putting humans on Mars has been a lifelong passion for me and the focus of my research career, so I am delighted to be here with you today.

In the past 40 years, we've learned an impressive amount about our sister planet, Mars. Thanks to NASA's scientific robotic missions, from Viking through Curiosity, we have more information about Mars than about any other planet, excluding our own. These missions have beamed back images of Mars' majestic and alien landscape and discovered liquid water beneath its surface. They've provided evidence that in ancient times there was surface water and an atmosphere rich enough to support life.

Just last month, researchers pouring over data from our Curiosity Rover identified complex, organic molecules in Martian sediment. Were they produced biologically, as similar compounds are here on Earth, and hence signs that Mars once bore life? 3.5 B years ago, Earth and Mars—sister planets, both likely had life. What went so terribly wrong on Mars? The answers, our scientific discoveries, tell us about life here on Earth and throughout the Solar System.

Scientific spacecraft and rovers will continue to make great discoveries and might someday answer the three enduring questions of exploration: (1) Are we alone? (2) Are there other habitable planets? (3) Is there life elsewhere, and what type? Landing women and men on Mars will accelerate discovery by many orders of magnitude. The first human missions to Mars will surpass the past 50 years of Mars robotic exploration. On just one human mission, we'll travel more than the 75 km cumulatively traveled on Mars by NASA's rovers.

Nothing inspires a nation—and future generations of innovators, my students, our students, who I call the "Mars Generation"—more than human spaceflight! Putting humans on Mars has been my dream for as long as I can remember, inspired by Apollo 11 as a young girl in Montana witnessing Michael Collins, Neil Armstrong and Buzz Aldrin being the first to land on the Moon. Apollo taught me to dream, to reach for the stars, and that anything was possible. I believe—I know—that we can make the leap, putting humans on Mars in the 2030s.

But dreams and willpower are not sufficient. We already have some of the brightest scientists, engineers, and technologists bringing their inventiveness and persistence to the 'Boots on Mars' mission. We've had bipartisan support from Congress

sional leadership and across administrations. We need to build on those foundations with a clear strategy and commitments to significant long-term funding.

Prioritizing among NASA's many important missions is never easy, and you all in Congress have to make tough choices if we are to succeed. We spend \$4 billion annually for Low Earth Orbit missions. They do important—critical—work. I know first-hand, my patented gravity loading countermeasure suit, flew on the ISS as a technology demonstration on astronauts in 2015 and 2017. But from an exploration point of view, and the desire to push humanity beyond what we think is possible, we've been stuck in LEO for far too long. We need to re-think the funding portfolio and timely investments to succeed in getting humans back to the Moon and onward to Mars.

Strategically, getting boots on Mars means figuring out the optimal roles for NASA, for private, commercial space ventures and for our international partners. Within NASA, we need to better integrate the Science, Space Technology, and Human Exploration portfolios. I recommend a synergistic Mars Program Office across all three with the necessary budget. No one nation can get to Mars alone, nor should we, on the timescale I envision. The benefits of the journey are for all of humanity—human exploration demonstrates the best of global cooperation.

My view of the best pathway to Mars breaks the strategy into three phases. Historically, we had Mercury, Gemini and Apollo. Currently, Phase I is the human exploration we are doing now, in LEO, on the International Space Station. Phase II is to get back to the Moon and deep space, demonstrating the technologies we need to sustain astronauts beyond LEO, namely, heavy lift launch capability, solar electric propulsion, deep space and surface habitats, and life support and mobility systems. We will fly to Earth-Moon orbit and land on the Moon. We need to evaluate the feasibility, cost, schedule, and investment portfolio, then make a decision and stay the course.

Phase III is self-sufficient travel to Mars. Explorers will be months away from home, we need to be completely autonomous without instant communications with Earth. We will rely on our technology investments in the 2020s in advanced propulsion, smart habitats, advanced human-machine autonomy, and novel radiation protection for this completely self-supporting journey to realize seamless interoperability between humans and our machines for scientific exploration. Why send humans to Mars many ask? When we're searching for life in the Universe, past or present, we look for liquid water that is critical to the evolution and sustenance of life. We have data from our Mars robotic rovers and orbiters that tell us that water was stable for as much as a billion years on Mars' surface, but that was about 3 billion years ago. This is the same time period that life evolved here on Earth in the oceans, formed from the building blocks of life—amino acids—that have been delivered all over the solar system by comets and asteroids. Astrobiologists tell us that the conditions on Mars were so similar to those on Earth that it's the most likely, closest place beyond Earth to have harbored—and might still harbor—life.

It will take focused research and technology development to implement Phase II and Phase III, to assure that we can lead human Mars exploration missions. At MIT, my students and I are working on some of these challenges. We investigate astronaut performance in low gravity environments and engineer solutions, like advanced second skin spacesuits and habitats that provide autonomy, sensing and self-repair. My technology demonstrated on ISS, could be furthered on the moon to provide greater astronaut mobility, ultimately, it will be technology realized during Mars exploration. Like many NASA investments, my research also has applications here on Earth, such as assisting people with locomotion and musculoskeletal disorders via soft exoskeletons.

In our lab and others across the country, the technology needed to get to Mars is under development. But most of it is still at a low Technology Readiness Level, or TRL. That's why it's crucial that we integrate Science and Space Technology as central parts of a NASA's Mars strategy.

Increase funding, keep it stable and develop a NASA portfolio that greatly furthers synergies among science, technology, and human exploration. This comprehensive, phased plan with the right coalition, will send us beyond low earth orbit, to the moon, and put humanity on Mars in the 2030s.

Senator CRUZ. Thank you very much and thank you to each of the witnesses for your testimony.

Let me start out with a question to the panel. Why Mars? Why should the American people care if we put a human being on the surface of Mars?

Dr. WHITSON. Well, I think we have a lot to learn about life and how it might happen and occur in other places and I think one key aspect of exploration, if you look at the philosophical part of exploration, is learning about life and where we come from.

But I think, you know, the big thing that benefits of exploration maybe are not so much those philosophical ones, even though that's what drives some of us, I think it's the technological advancements.

Doing these difficult things is going to improve our capability as a country, as a nation, as a world on solving problems here on Earth and increasing technology, having people interested in the sciences, studying more and learning more things in the sciences is going to be a benefit here on Earth.

Mr. BRUNO. I agree with everything my colleague has said. I'd just like to add that when you want to establish a fundamental scientific understanding of a complex system like our own planet, it is crucial to be able to study similar, in this case, celestial bodies in a different state of their evolution.

Mars uniquely offers us that opportunity to have more than one data point in a different state than our own planet is in today.

Mr. CARBERRY. It's interesting. My organization actually has a whole program on this very question. We released a document about a year ago where we had about a dozen different individuals from different disciplines. We had Hollywood actors, we had scientists, we had, you know, science fiction writers, STEM educators, just every imaginable discipline, you know, explaining why we did, and this is one of the biggest questions, why I think the whole space community sometimes doesn't answer the question well, because there are so many good answers.

When we went to the Moon, really there was one primary answer, to beat the Soviet Union. It was easy to articulate. Let's beat the Soviets.

Today, we have so many more and so many better reasons. The inspirational value, if you go around speaking to kids around the country, you realize they're really inspired, you know. The technologies that will be required for it, plus, you know, of all the places that humans can go in the Solar System, Mars is best-suited for humanity.

As the discovery today of the liquid water below the surface of Mars will show, we can live off the land on Mars, you know. While there are resources on the Moon, they're not nearly as abundant and there's no atmosphere there. So Mars is really the best option for sending humans for sustainability that we can achieve any time in the near future.

Dr. NEWMAN. I agree with all of my colleagues, but Mars and Earth, each 4.5 billion years old are sister planets. So Mars is really habitable, warm, wonderful, and then probably 3.5 billion years ago something went terribly wrong.

Why is that so important? It teaches us about Earth, because it teaches us about life. So it's a fundamental question about life and we follow the water. So we're going to follow that water that we just found today right down into the sub-surface because you look for those amino acids. Those amino acids have been spewed all over by common sensors. They're all over the universe.

So we're looking for life. So the surface of life, as was mentioned, is close, not too closest place to go, best place to go. We will find this answer about life other places, past or present, in the universe. That will fundamentally rewrite all of our scientific textbooks, and I just can't think of anything better to do.

Senator CRUZ. In your judgment, what are the biggest scientific and technical hurdles that stand between us and landing safely on Mars, and are we on trajectory to clear those hurdles and get to Mars and back safely by the 2030s?

Mr. BRUNO. I'll go first. From a rocket scientist point of view, it's actually very difficult to go to Mars and I've placed those challenges sort of into two buckets.

One is simply the trip. The orbital mechanics of traveling to Mars is a challenge. The other are the human factors and the safety aspects of going to Mars because it is a very long deep space transit.

So if I start with the first aspect, just to give you a feel for it, our two planets are always in relative motion and the geometry of the Mars orbit is especially challenging because not only is Mars going around the sun at only half the rate that the Earth is, it's also very eccentric orbit.

It's highly elliptical and so the distance between our two planets can be as small as a gigantic 35 million miles or as large as 250 million miles, and the only times we can really practically go to Mars is when the Earth is catching up and about to surpass Mars and at that point, that's really our only launch window where we send a spacecraft to sort of tangentially drift off and later intercept with the Martian orbit and then do that rendezvous. Those opportunities only come around once every two years because of the relative motions of our planets.

The orbital accuracy required to achieve that defies sort of human imagination. It's hard to relate to what we truly have to achieve. So I did a little quick math last night to try and scale all that down so it fit on the Earth so that we could sort of relate to it a little bit better.

The way it works out is if we place this on Earth scaled down, it's much like hitting a hole in one, for those of you who are golfers, out at California's beautiful Pebble Beach, teeing off from Paris, while standing on a moving pickup truck. That's a pretty difficult problem.

You are sending this spacecraft on a fixed trajectory to travel as much as 300 million miles way back at Earth. That's when you let it go and it heads off. So the orbital mechanics piece is very, very difficult.

The next challenge we run into is the transit time and the environments that our Mars astronauts will be exposed to. Because this is deep space travel, they will be experiencing radiation environments that are four times more severe than what we see on the International Space Station which is largely still protected by the Earth's magnetosphere.

Because of the extreme duration of the mission—now we can get to Mars on the right 2-year cycle theoretically as fast as 3 months but most practical missions are really going to take more like six to eight months.

So because of that duration, our astronauts that go to Mars and conduct a mission and come back are going to see at least a hundred times, probably more than a hundred times the total radiation exposure that Apollo astronauts experienced going to and from the moon and so it's going to be absolutely vital that we develop ultralightweight shielding materials and procedures and con-ops that will minimize the exposure of our astronauts to that environment.

We know only some of the health effects associated with that kind of radiation exposure and if they're not protected, they're pretty scary. We understand there will be significantly increased risk of cancer, potential for nerve damage, cognitive impairment, and even cataracts, and so we cannot tolerate that. We have to keep our astronauts safe and within reasonable risk limits on that trip, which is also why I believe the Moon in a way is on the way to Mars because it affords us a platform to do that research, develop these technologies, qualify them nearer to home, three to six days from home, before we commit that trip that's going to take at least a year.

Senator CRUZ. Thank you.

Senator MARKEY. Senator Nelson.

Senator NELSON. Thank you, Mr. Chairman.

Thank you, Mr. Bruno. That was a most articulate explanation and is in response to a former statement by Mr. Carberry that they were going to send a quick expedition there for two weeks on the surface. That's assuming that you've got the planets aligned and that you can get there. Therefore that begs the question: don't we have to have a faster propulsion to get us there?

So, Drs. Newman and Whitson, how much of a priority should NASA place on the space propulsion technologies and other than that, what is the benefit of shortening the time to get to Mars?

Dr. WHITSON. Well, probably the biggest benefit of shortening the time is reduced radiation risk. It's easiest to protect the crew from radiation risk by not exposing them for as long of periods of time. So that decreases it, and then once you get on Mars, you could bury your habitat and provide some protection that way, once you got there.

So I do think getting there faster is a big part of the solution and I do think that there will still be risk, radiation risk. So I think developing other alternative medical or biomedical-type solutions might also need to be necessary, as well, just to have that as a backup, but I do think getting there faster will help for sure.

Dr. NEWMAN. I agree. I'd love to shorten the time by half, so the investments, again the technology investments in advanced propulsion, I think we can still make it even if we use conventional, you know, chemical rockets.

One technology we haven't talked about is inter-descent landing. It's critically important. Right now today, we know how to land one to two metric tons. It's fantastic what we do with Curiosity Rover. Mars 2020 coming up, but, truthfully, we know how to land one to two metric tons. So your human mission start at the baseline working on 20 metric tons, 40, I believe. How about five metric tons, 10 metric tons? How about modular designs? How about new kind of architectures? But that is a step change. So that's the limitation right now in our understanding but that's why we're studying it.

I agree with the propulsion. The radiation, there's some great research going on. I'm optimistic. I mean give us 10 years. Sure, we need shielding, better materials. We're on it, but we've got to look at biology, as well. This will help our view of Martian astronauts but that will fundamentally help cancer research here on Earth.

So if you want to talk about synergies and it's happening and I think within the decade or two, so really look deep into the biology and the genetics of this is going to help protect our astronauts but, as well, it could be fundamental for life here on Earth.

Senator NELSON. So, Mr. Bruno, what is the importance to industry that NASA have a stable plan to get to Mars instead of a herky-jerky approach?

Mr. BRUNO. Yes, stability in terms of a clear plan and direction set of priorities and funding stability is absolutely vital.

In industry, if you don't have the work for your people to do, they don't stay on the team. They scatter and they go to other industries, they go to other activities, and human capital is everything to this mission.

You know, the physical things are important but those are the easiest things to come by, launch pads, tooling, factory. That's the most replaceable. Know-how, expertise and experience, that's very perishable and that is the most important thing.

So it is absolutely the Number One priority from an industrial point of view.

Senator NELSON. Dr. Whitson, other than the exposure to radiation, what are we finding out by your personal experience of many days in near-zero G that we're going to have to overcome to go on a mission to Mars?

Dr. WHITSON. Well, in engineering terms, I'm the fleet leader right now. I've got the most revolutions, the most radiation, but I do feel that we have come a long ways. We've learned a lot of things. We still are learning some things. You know, we're able to protect bone mass, which is a big deal. We don't know for sure if it's all going to be the same bone quality because it's always constantly being remodeled. So we're still doing more detailed studies on that but we're testing different types of drugs because we have a platform where we can test those new drugs and understand them and easily by the time we start sending people, we will have complete solutions for those, I think, and we will be ready.

I think really the biggest hurdle right now is radiation and, you know, we do have some changes in the vision, but I think we're getting a handle on even those now, as well.

So I think we will be ready and we do have a roadmap of different types of investigations and answers that we need for the Mars missions, and I'm confident that we'll get there with platforms, like what we have on the ISS and on the future Gateway. That could also be an excellent platform for some further research as we extend.

Senator NELSON. Thank you. Thanks.

Senator CRUZ. Thank you.

Senator Markey.

Senator MARKEY. Thank you, Mr. Chairman.

Dr. Newman, you spoke in your opening statement about the importance of human exploration rather than relying upon robots alone.

Why is that important? Why is human exploration so important in substitution for robots or other technologies, given every other industry moving to automation?

Dr. NEWMAN. So it's really our humans and robots and our machines together. We really are now in a world versus global exploration and it's humans and machines. Mars is so far away. It's a communications. So we have to change our—we call them con-ops, the mission operations. Our humans have to be completely autonomous.

I mentioned before just the inspiration, lifting everyone up. Let's just do the hardest thing that is possible to do because we know we can do it and that'll raise everybody up.

I've spent my whole career in STEM education. I call it STEAM now because I want to bring in the Arts. I bring in the Makers because every little girl and boy I talk to says you're in it, you know. You want to get humans to Mars inspires every single one of them.

The human capability, when we get to Mars, we will surpass what we've done for 50 years with rovers, I mean, I love—I'm a robotics myself, but we've only covered—you know, these are slow and we only go an inch at a time. So humans are—we're really mobile. We're really good. You know, we are going there to explore. So you can just cover so much terrain and Apollo made a huge difference when we gave the rover, so the humans on their machines in that rover, and we just doubled and tripled our range of exploration. So I really do see it as time for humans. We'll keep doing the precursor robotic missions but when we really get there, if we haven't found life already, I think we'll find it very quickly then with human and robotic missions together and synergy.

Thank you.

Mr. BRUNO. Could I add one thought to Dr. Newman's remarks?

Robots are really, really good at doing one thing. We program them to do one thing. They're great at it. They can be better than a human being at that. What human beings are good at is doing many things and many unanticipated tasks. There's absolutely no replacement for a Buzz Aldrin, boots on the ground. When you get to Mars and you find the conditions are not exactly as you anticipated or you discover something you want to investigate further, a person can do that. We have to send another robot from Earth if we want to do that.

Senator MARKEY. So thank you, Buzz Aldrin, for everything you do.

I agree with you. We need boots on Mars, not just bots on Mars. We need to ensure that we do both, but the boots on Mars is the key.

Can you talk a little bit about the benefits to humanity of going to Mars? What do you see as the derivative benefits, Dr. Newman?

Dr. NEWMAN. Thank you. I think it's globally hard to really—you can't put a price tag. You can't put importance on how Apollo fundamentally changed all of us. I am sure that I am here today because I was a young girl watching Apollo 11. I mean, it was so in-

spirational, just everything, the best of humanity. So that's how I look at the Mars mission now.

We get humans there with all of our great science. It'll lift us all up. It will open up the eyes and the doors. So I really do see it as a global cooperation and lifting up humanity. Who knows what we can do. We have some real challenges. We have some real scientific and technology challenges here on Earth and I liked the point that was made perhaps, too.

We need more of an N of 1. We just have Earth now. We have a whole Solar System out there. We have a lot happening on Venus and Mars. So again just putting that all together and just saying the Solar System is ours, do it together. We share that. What a great day today with the science discovery. We're all going to take credit for that, right? It's Italian lead investigators but we're all in this together because, guess what, NASA's funded most of that science to make that happen. So that's how I look at it. It really is for all of us. It's something that is completely inclusive and it's for everyone and it just helps us, you know, raise our game.

Mr. CARBERRY. I'd like to actually comment on that.

Senator MARKEY. Just a minute. Mr. Bruno, can you comment a second on what opportunities exist in SIS lunar space that can benefit us down here?

Mr. BRUNO. SIS lunar space promises the potential of a post-scarcity human future. It's a complete paradigm change for our civilization and for what it means to be a human being.

Today, we think on Earth about fixed resources in a world in which there is ever-more scarcity as we go forward but when we look out into SIS lunar space, just a scant week's journey from where we sit today, there are such resources in such abundance that it truly defies human imagination.

There are a thousand years of total global production of industrial metals just in the asteroids between here and the moon. There are more precious metals than have ever been mined in the history of humankind.

So when it is practical and affordable to access those resources, we're looking at a human future that is completely different than what we have seen before.

Senator MARKEY. And, Mr. Carberry, if I may, international cooperation, how important is that?

Mr. CARBERRY. Extremely important. We've been actually doing a number of programs on this. We did a partnership with the UAE recently. It has been one of our primary objectives to try to really make sure human exploration to Mars is international. It should be led by the United States but our international partners want us to lead. They continually say at various events that they will follow along, if they can see that we are actually leading the path, but they have concerns that we keep changing directions. They're not sure that we're going to stick with the directions.

So I think it's extremely important not only to build that sustainability but also to offset some of the budget, as well. I think we absolutely need international participation with Mars missions.

Senator MARKEY. Thank you.

Thank you, Mr. Chairman.

Senator CRUZ. Thank you.

Senator Peters.

**STATEMENT OF HON. GARY PETERS,
U.S. SENATOR FROM MICHIGAN**

Senator PETERS. Thank you, Mr. Chairman, Ranking Member, for this fascinating Committee, and certainly appreciate the testimony.

I want to pick up on Senator Markey's question about international cooperation, particularly in terms of how we pay for all of this.

I am a huge booster of this. I think we've got to move forward. I share, Dr. Whitson, some of your philosophical dreams, as well. I think that's an important part of it but also I'm a dollars and cents guy, so I have to go back to my constituents and make the case as to why these investments are important and also how we can do this in an efficient way, and I think most taxpayers will say why would the U.S. Government and taxpayers do this all by ourselves, notwithstanding all the wonderful benefits, which I'll agree. I'm not arguing against any of those benefits.

So my questions are related to how do we find those partners. Mr. Carberry, you mentioned the international partners, but before I go to that, it seems to me that when we think about the advantages of this journey, beyond the philosophical ones, it is technological advancements. We know what happened in the Apollo Program and all of the spinoffs that were there that benefited our society immensely.

Because of the extreme and difficult technological challenges for Mars, I suspect those advancements will be even greater and there will be some sort of exponential amount of that, but I want to get your sense.

Is it possible to have private industry partners because often with a lot of this technology. It's not happening within government. It's artificial intelligence that's not happening to the same extent within government labs as it is in the private sector, which is moving very rapidly.

I'm from Michigan. Autonomy, self-driving vehicles, and autonomous systems are moving incredibly rapidly in the private sector, as well. What sort of opportunities do you think we have for NASA to partner with private industry where there's a financial benefit for them as well as a benefit for the mission? Is that possible? How would we think that through?

Mr. CARBERRY. I think there are tremendous opportunities. I think when we go to Mars, it will be NASA-run, but there are tremendous opportunities to integrate all these new commercial entities.

We already are doing it and, of course, all the people developing the hardware are commercial people that make it sound like it's all the government that's actually building all the hardware. They're not. But as you mentioned, technologies, like AI or VR, these are all industries that are currently working on technologies that are interested.

We just had a conference where we highlighted a lot of these technologies that will be integral when we go to Mars, not only when we're actually there for the astronauts and the scientists

back on Earth, but ways to bring along the public along with us, you know, through all these new technologies, but also areas, kind of like with that benefit to Earth.

We were recently doing programming in partnership with the agriculture industry. We need to learn how to grow food on Mars, utilize water, and so there are all these different areas of technology in order to be able to eat, areas which you wouldn't imagine right now. You don't think of traditional aerospace industries but this really runs enormous range of different types of industries and capabilities that will be required to go to Mars and will come back and benefit us as we learn to do better agriculture in arid locations, like Mars, or extracting water or power, you know, better power utilization.

So I see this as critical and as we move forward, we need to integrate this in the overall plan, not just internationally, but find ways to build these public-private partnerships.

Senator PETERS. In my comments, I'm saying it's different when you have private industry investing as opposed to being a contractor. I get it that they're selling their services as a contractor. They're doing it. The government's contracting it.

But how do we get a company to say we want to actually invest in the Mars mission because we'll put our own money in? We're not expecting any taxpayers to contract with us. We're expecting we will invest our own money in this because we believe a successful Mars mission pays off to our investors.

Mr. CARBERRY. They already are.

Senator PETERS. So the private business is investing now with—

Mr. CARBERRY. Private industry is investing in a lot of different technologies, very enthusiastic. Obviously, there are a lot of major companies you've heard of that are investing their own funds, you know, to advance Mars missions. But going back to these other types of technologies I mentioned, like VR, AI, but also agricultural elements, I know of a number of companies that are actually—they're excited about it. They're investing in it. They want to take part. Yes, they're going to want a contract at some point in the future. They hope to be part of it but it's not all about money.

They're excited about participating in Mars exploration and helping to create a more successful mission. So there are companies that are investing right now. Do we need more of it? Of course we do. We want to find ways to stimulate that but it's already happening.

Mr. BRUNO. So if I might add to that, this is a special opportunity. There are two types of private investment that you might experience relative to space.

There are companies making investments in order to position themselves to win government contracts, which means that ultimately the government is still paying for all of this. Then there are investments that companies make because there is a commercial business case that can be closed.

A few moments ago, I referred to the tremendous natural resources and the potential for commercial activity in SIS lunar space. Because going to Mars needs to pass through, if you will, the moon in order to do research and develop the key technologies, that

creates an environment that is perfect for public-private partnerships for companies that want to leverage that research, to then develop natural resources from the moon, to mine ice for propellants, to tap the industrial metals that are in the near earth objects, and invest their money because they can close a commercial business case within a relatively short horizon by teaming with NASA, furthering NASA's goal, while enabling this SIS lunar economically independent and self-sustaining econosphere.

Senator PETERS. Great.

Dr. NEWMAN. And piggybacking on to that, I agree with Tory, and so when we look at the public-private partnerships, I had the pleasure to be in charge when I was at NASA with 120 countries and over a thousand of them, so that's a lot, and it just depends. A lot of it has to be government-led, I do believe, space agency-led, when we talk about Mars. That's what exploration is about.

When we get closer to home, low earth orbit, the smallest sat business case, they close, they close. So we need to further that. That's where industry is going to step up and the business case really closer to home and SIS lunar. It seems that those business case closes, but when we talk about Mars have to think that again government leadership, really moving out to say this is what we're going to do as the U.S., and they'll be great private partners and there is a new model under our public-private partnerships.

Industry is really coming to the table and they really are putting in a lot of their investments. So I think we have to get that model right in the public-private partnerships but destination, you know, how far away we go from Earth really makes a big difference in the distance case.

Senator PETERS. Right. Thank you.

Mr. BRUNO. I would even add one more thought, which is, you know, in his opening remarks, Senator Nelson talked about needing to be careful that the endeavor of going to the moon does not distract us from our ultimate goal of going to Mars.

These two things are linked. There's logistic support and activity around the research that will happen at the moon in order to go to Mars that will allow NASA the opportunity to quickly transition those activities to commercial companies for commercial uses and that is how NASA will be able to stay focused on Mars as the ultimate goal and not get bogged down in logistics associated with being in vicinity of the moon.

Senator PETERS. All right. Thank you.

Senator CRUZ. Well, let me echo something Mr. Bruno said in terms of talking about the opportunities of commercial space.

One of the reasons we've seen some of the advances we've seen in recent years is because of the very beneficial collaboration we've had between the public sector and NASA and the commercial space industry, and at the end of the day, the commercial sector is going to be able to invest billions more in dollars to getting this job done and I share your optimism about the potential and, indeed, I predicted before that I think the first trillionaire that we see will be made in space. I don't know who it will be and I don't know what they will discover or what they will accomplish but I think it is every bit as vast and promising a frontier as the New World was some centuries ago.

One of the things that has been gratifying in this time of deep partisan division on so many issues is that space has not been one of them, that we've seen under President Obama, we've seen under President Trump, a cooperation in the Senate, in Congress, between Democrats and Republicans, committed to maintaining space exploration and America's leadership.

In the past several years, we passed bipartisan legislation authorizing NASA, commercial space launch legislation, one signed by Obama, one signed by Trump. We're in the process of taking up, and I hope passing, yet a second round of commercial space launch legislation that I just recently introduced, and the intention is to take up a longer-term NASA authorization bill.

The one we passed last year was the first one in seven years. It was an important milestone, but it was designed to ensure continuity. This next NASA authorization, the hope is that it will reach further and be bolder in aspirations and so I guess the question that I would ask this panel is if the objective, as all seem to agree, is getting to Mars and getting to Mars by the 2030s, are there elements that any of you think are particularly important for Congress to include in the NASA authorization legislation to facilitate that, to accelerate that, to remove barriers that may stand between us and getting to Mars?

Mr. BRUNO. I would say two things and one of them you have already alluded to, sir, which is stability in the national goals and the funding associated with that, so that there are not fits and stops and starts and loss of vital workforce, as I alluded to a moment ago.

The other thing that I think we need to be mindful of I mentioned in my opening remarks. From the standpoint of the launch industry, this is a flat marketplace, if anything, expected to have a temporary dip. It's essential that we have a healthy industrial base.

The thing that's unique about our system in America is that we have a partnership between government and industry. NASA and its industry partners work together. That's why we have the greatest technology in the world. It's why we can aspire to tremendous goals, like putting boots on Mars and putting a permanent presence there.

The industrial base must be taken care of and so at a time when the other commercial demands for launch, for example, are low, we need to make sure that we have a healthy competitive set of companies in America and we do that by keeping those investments at home in our own industry.

Mr. CARBERRY. One of the critical things, I think, that is actually needed is something we've gone over in one of our previous workshops that brought aerospace professionals together and we created—kind of outlined probably about a dozen long pole technologies.

These are technologies we need to start working on pretty much immediately if we have any hope of landing humans on Mars in the 2030s. These include entry, descent, and landing, as Dr. Newman mentioned, and other things, like Eclis, you know, Assent. Some of these technologies are going to take quite awhile to actually

achieve and we can't just wait until we're at Mars and then say, oh, now we have to figure out how to land.

So we have to start working on them now. We have to outline which ones, plus outline which ones have direct overlap with lunar exploration, first defining what lunar exploration means in the context of what we're going to do, but then figure out which ones have direct overlap, you know, so we can actually start working on those specifically.

Another thing, which was already actually mentioned in the 2017 Authorization, better integration, better integration with the mission directorates and the partners to make sure they move ahead efficiently, so like human exploration and science and technology can all work in tandem, you know, toward that one goal. So there are probably dozens of other things, like I mentioned, but I'll leave it right there.

Thank you.

Dr. NEWMAN. Yes, constancy of purpose, we like to call that, advanced propulsion, smart habitats, incorporating all of that autonomy that is, you know, we're on the edge of right now, entry, descent, landing, bio-regenerative life support systems hasn't been mentioned, suits, in situ research utilization. That's what we do when we get to other planets. That's what explorers always do. We live off the land, so we have to figure that out. We have to make the habitats out of our basalts.

When we it comes to humans, radiation is the Number One, need to work on that more, but the human factors, the mental well-being of folks far, far away, can't trivialize that. We need to take care of the safety and wellness of our astronauts, musculoskeletal, we're getting a handle on that, and my final comment is this integration. That's really functional. That's really the functional organization. That's hard because we have to—we can't have the stovepipe. So we really need science, technology, human exploration, one pot of money. So that's why I call the Mars Program Office. That would be the true integration. I think we could get there.

Mr. BRUNO. If I could add one more thought to one of the things that Dava brought up, I hear a lot of debate and assertions in this question that, well, you know, this is a great human endeavor and there's going to be risks and so we're going to tolerate people being lost and it is true that there are inherent risks in going to space.

Space is a physics-defying act and it is not possible to make it risk-free. That's a fact. However, there is no reason that we need to take unnecessary risks with human life. Our astronauts are our sons and daughters, mothers and fathers, husbands and wives, and it is not acceptable that we take risks with their lives and well-being that we can avoid and apply our ingenuity and our industrial and technological might in order to mitigate.

Dr. WHITSON. Well, I'll go back and just reiterate that the one most important thing is constancy of purpose. We have to have a vision that lasts more than one Administration. We have to have a budget line that will support those goals and objectives that we are striving to reach and to me, I think that will help us solve a lot of the problems.

Senator CRUZ. Well, thank you very much. Let me thank each of the witnesses.

I would note on constancy of purpose that has been one area where we have seen wide agreement in Congress and in the Senate and, indeed, we began the NASA authorization endeavor in the previous Administration and continued it through to this Administration precisely to avoid the sort of cancelations we've seen in the past, whether with Constellation or otherwise, and the billions of wasted dollars and frustrated man hours that were lost.

And so let me thank each of the witnesses. This has been, I think, a very productive and informative hearing. Thank you for your lifelong commitment. This is a labor of love. Nobody is confused that you're doing this for anything other than passion, and we will keep this hearing record open for two weeks. There may be Senators who submit follow-up questions and the witnesses are asked, if there are follow-up questions, to promptly respond to those.

And with that, this hearing is adjourned.

[Whereupon, at 4:31 p.m., the hearing was adjourned.]

A P P E N D I X

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. BILL NELSON TO DR. PEGGY WHITSON

Question. In the International Space Station (ISS) transition plan, NASA outlined how the ISS will be used to prepare for the journey to Mars. NASA's proposed lunar gateway could also play a role, but it will reside much further from Earth in the harsh deep space radiation environment outside Earth's Van Allen belts. When it comes to doing research and developing technologies for human missions to Mars, is there anything we can do on a lunar platform that wouldn't be safer and cheaper to do on the space station?

Answer. I believe that the Gateway to the Moon and beyond will give us a strategic presence in cislunar space that will drive our activity with commercial and international partners and help us further explore the Moon and its resources and leverage that experience toward human missions to Mars. We also will begin to build the in-space infrastructure for long-term exploration and development of the Moon by delivering to lunar orbit a power and propulsion element as the foundation of the Gateway. In-space power and propulsion and deep space habitation are central to future human exploration. Development and deployment of these capabilities will be a focus of the early-to-mid 2020s, leading to crewed missions beyond the Earth-Moon system, including to the Mars system.

NASA has already taken steps in a new campaign in Advanced Cislunar and Surface Capabilities (ACSC) that will once again establish U.S. preeminence to, around, and on the Moon. Working in parallel with scientific lunar exploration, and in addition to the initial flights of the SLS, Orion, and the elements of the Gateway, NASA is planning to develop a series of progressively greater robotic lunar missions to the surface of the Moon. This will also serve as a foundational training ground to prepare for later missions to Mars.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. GARY PETERS TO DR. PEGGY WHITSON

International Cooperation. The U.S. will likely not be alone in our quest to put humans on Mars. With more potential international partners now growing space programs than ever before, putting together a coordinated effort will be challenging. As administrations change, so do our priorities in space, making it difficult for our potential partners to be assured of long-term plans.

Question. What sort of plans or agreements would be helpful in building a coordinated international coalition for a mission to Mars?

Answer. The 14 space agencies participating with NASA in the International Space Exploration Coordination Group (ISECG) have reached consensus regarding the importance of a Gateway in expanding human presence to the Moon, Mars and deeper into the solar system. Through partnerships both domestic and international, NASA will bring innovation and new approaches to the advancement of U.S. human spaceflight goals. International partnerships with Japan, Europe, Canada, and Russia bring over 30 years of Space Shuttle and International Space Station (ISS) experience and have been a vital component of U.S. space exploration. NASA expects additional capabilities could be provided by other international partners. The Gateway offers a compelling vision of the future that will attract contributions from U.S. private sector companies and international partners.

Sample Return. A recent article published in the journal *Science* announced the discovery of organic molecules in ancient Martian rocks. These were the results of data coming from the Curiosity rover. Just think how much more could be realized with in-depth studies in laboratories here on Earth. The Decadal Survey for Planetary Science covering 2013 to 2023 states the start of a sample return mission from

Mars should be the highest priority mission for NASA. Yet we still have no firm commitment to the Mars Sample Return mission in the FY19 budget.

Question 1. When will we need a commitment or specific plans for sample return to maintain leadership in this area?

Answer. My understanding is that NASA's FY 2019 budget request enables planning for a potential Mars Sample Return mission incorporating commercial and international partnerships, including \$50 million for specific studies and technology development aimed at Mars sample return mission.

Question 2. Should we prioritize a multi-mission effort targeting the return of large Martian samples to Earth sooner rather than later, or would this be to the detriment of getting humans on Mars?

Answer. I anticipate that technologies that will inform future crewed missions and launches will be a natural outcome of preparing for a potential sample return mission, so I do expect significant value in pursuing Martian sample return.

Manufacturing in Space. The infrastructure build out needed for a human mission to Mars, especially for when our astronauts reach Martian soil is a complex and complicated challenge. NASA has worked with America Makes—the Manufacturing USA institute focused on additive manufacturing—to hold a competition for 3D printing of habitats using indigenous materials. An alternate approach to indigenous materials would be to pre-place materials and equipment on Mars, but that may take some technology development for landing of heavy payloads.

Question. What do you think is the most likely solution for manufacturing on Mars and how much is being invested in this area right now?

Answer. NASA and partner Bradley University of Peoria, Illinois, selected five teams to share a \$100,000 prize in the latest stage of the Agency's 3D-Printed Habitat Centennial Challenge competition. Winning teams successfully created digital representations of the physical and functional characteristics of a house on Mars using specialized software tools. The teams earned prize money based on scores assigned by a panel of subject matter experts from NASA, academia and industry.

As NASA advances deep space exploration, reliable life-supporting habitats will be essential. But creating a structure on the surface of Mars is an extraordinary challenge considering the extensive limits on transporting materials and the differences in atmosphere and landscape. The 3D-Printed Habitat Challenge aims to further the progression of sustainable shelters that will someday occupy the Moon, Mars or beyond by pushing citizen inventors to develop new technologies capable of additively manufacturing a habitat using indigenous resources with, or without, recyclable materials.

The challenge, which began in 2014, is structured in phases:

- *Phase 1*, the Design Competition, required teams to submit architectural renderings and was completed in 2015. (\$50,000 prize purse)
- *Phase 2*, the Structural Member Competition, focused on material technologies, requiring teams to create structural components. It was completed in 2017. (\$1.1 million prize purse)
- *Phase 3* (current), the On-Site Habitat Competition, challenges competitors to fabricate sub-scale habitats, and has five levels of competition—three construction levels and two virtual levels. For the virtual levels, teams must use Building Information Modeling software to design a habitat that combines allowances for both the structure and systems it must contain. The construction levels challenge the teams to autonomously 3D-print elements of the habitat, culminating with a one-third-scale printed habitat for the final level. (\$2 million prize purse)

The 3D-Printed Habitat Challenge is managed through a partnership with NASA's Centennial Challenges program and Bradley University. Bradley has partnered with sponsors Caterpillar, Bechtel and Brick & Mortar Ventures to administer the competition. NASA's Centennial Challenges program is part of the Agency's Space Technology Mission Directorate, and is managed at NASA's Marshall Space Flight Center in Huntsville, Alabama.

Gateway. The Orbital Gateway will certainly be an important component in deep space exploration, but there is still some uncertainty about its specific functions.

Question 1. How is the Orbital Gateway specifically being designed to enable future exploration of Mars? For example, will it serve to address major technology needs like long-term life support, will it provide infrastructure for communication and in situ resource utilization at Mars? Or will it function more to service missions to the Moon?

Answer. Sustainability will be a key component of our future exploration. Together with the Space Launch System (SLS) and Orion, the Gateway is central to

advancing human space exploration goals in a sustainable manner. Gateway is the unifying single stepping off point in our architecture for human cislunar operations, lunar surface access and missions to Mars. The Gateway is necessary to achieving the ambitious exploration campaign goals set forth by Space Policy Directive 1.

The Gateway to the Moon and beyond will give us a strategic presence in cislunar space that will drive our activity with commercial and international partners and help us further explore the Moon and its resources and leverage that experience toward human missions to Mars. We also will begin to build the in-space infrastructure for long-term exploration and development of the Moon by delivering to lunar orbit a power and propulsion element as the foundation of the Gateway. In-space power and propulsion and deep space habitation are central to future human exploration. Development and deployment of these capabilities will be a focus of the early-to-mid 2020s, leading to crewed missions beyond the Earth-Moon system, including to the Mars system.

NASA is pursuing a new campaign in Advanced Cislunar and Surface Capabilities (ACSC) that will once again establish U.S. preeminence to, around, and on the Moon. Working in parallel with scientific lunar exploration, and in addition to the initial flights of the SLS, Orion, and the elements of the Gateway, NASA is planning to develop a series of progressively greater robotic lunar missions to the surface of the Moon. This will also serve as a foundational training ground to prepare for later missions to Mars.

Question 2. What timeline is expected or necessary for development of the Gateway to support the exploration of Mars?

Answer. NASA plans to launch the first element of the Gateway—its power and propulsion module—in 2022, with completion of the Gateway by 2025.

Technology Development. One of the reasons given for pursuing bold exploration missions is that the technology developed to enable the mission transfers to the commercial sector and improve the everyday lives of people right here on Earth.

Question. In prioritizing putting humans on Mars, what sorts of unique technologies will be developed that might benefit everyday life that would not be realized if we concentrate only on additional work in low Earth orbit or other missions to the Moon?

Answer. NASA's FY 2019 budget request focuses investments in research and technologies applicable to deep-space exploration, prioritizing environmental control and life support; power and propulsion; advanced materials; communications; navigation and avionics, robotic assembly and manufacturing; entry, descent and landing; autonomous systems and enabling humans to live and work in the space. As you know, technology drives exploration, both human and robotic, and helps us solve problems in space and on Earth. It lays the groundwork for our future missions and addresses many needs, including how we'll live in space and how we'll get there, and will support the growing U.S. commercial space industry. NASA will focus on applications of technology toward deep space exploration and innovative ways to further our goals from concept to testing and flight.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. BILL NELSON TO
SALVATORE T. "TORY" BRUNO

Question 1. The 2017 NASA transition bill required NASA to define a plan for reaching Mars, including "interim missions and destinations." This plan is more than seven months late. Does industry understand how NASA plans to get to Mars and what role industry will play? From an industry perspective, how important is it for NASA to have a step-by-step plan for reaching Mars versus a more flexible approach?

Answer. ULA understands the supporting role we will play in sending humans to Mars—by providing transportation for scientific missions that will precede humans to learn as much as we can in support of human missions; by supporting the initial flights of SLS with the Interim Cryogenic Propulsion System; and by ensuring a stable industrial base for our Nation's flagship programs.

Currently NASA is maintaining a great deal of flexibility. Flexibility is a good thing, but a plan will be critical to success. The most valuable resource for a mission of this magnitude is human capital, and if your workforce does not believe you are on a clear path with stable funding, they may start to move elsewhere and put the mission at risk.

Question 2. The administration has proposed a new lunar exploration program, including a space station in lunar orbit and a series of lunar landers, progressing to a human-rated lander in the late 2020s. What direction should Congress provide

to ensure lunar exploration missions most effectively advance a human Mars mission?

Answer. Congress must work with the Administration to ensure that any government-driven requirements for lunar surface operations be designed in a way that can also be applicable to future operations on the Martian surface. Additionally, continued program and funding stability will be critical to ensuring delays do not drive a stake between our lunar and Martian exploration plans.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. GARY PETERS TO
SALVATORE T. "TORY" BRUNO

International Cooperation. The U.S. will likely not be alone in our quest to put humans on Mars. With more potential international partners now growing space programs than ever before, putting together a coordinated effort will be challenging. As administrations change, so do our priorities in space, making it difficult for our potential partners to be assured of long-term plans.

Question. What sort of plans or agreements would be helpful in building a coordinated international coalition for a mission to Mars?

Answer. International partners will be necessary to reach Mars, and because the United States will lead, these partnerships will further strengthen our geopolitical standing. Having said that, it is important that we use caution when relying on other nations for any system on the critical path, as the political will to support space exploration in those countries can wane. Additionally, we must ensure we are protecting our own industrial base, particularly in launch, by taking advantage of the systems in which our Nation has invested billions. It is important that NASA-funded payloads and missions launch on U.S. rockets from American soil, and that we encourage our international partners to leverage our launch and exploration capabilities wherever possible.

Additionally, the U.S. has and will continue to set the international norms for safety, mission assurance and cooperative standards, so we need to continue to be mindful that our actions often set precedent for the international community. With that in mind, NASA must prioritize safety and mission assurance throughout its mission planning, procurement and operations.

Sample Return. A recent article published in the journal *Science* announced the discovery of organic molecules in ancient Martian rocks. These were the results of data coming from the Curiosity rover. Just think how much more could be realized with in-depth studies in laboratories here on Earth. The Decadal Survey for Planetary Science covering 2013 to 2023 states the start of a sample return mission from Mars should be the highest priority mission for NASA. Yet we still have no firm commitment to the Mars Sample Return mission in the FY19 budget.

Question 1. When will we need a commitment or specific plans for sample return to maintain leadership in this area?

Answer. The United States remains the only nation to have successfully landed on the Martian surface. I would point out that all of those missions flew on Atlas, Delta, or their heritage rockets. We are not in any immediate risk of ceding U.S. leadership in this area. Having said that, a credible plan sooner rather than later would benefit scientific research and help shape requirements on any sample return that can benefit future human exploration of the surface.

Question 2. Should we prioritize a multi-mission effort targeting the return of large Martian samples to Earth sooner rather than later, or would this be to the detriment of getting humans on Mars?

Answer. I believe it is possible for NASA to conduct multiple Mars sample return missions without negatively affecting our efforts to put humans on Mars. In fact, these missions will provide information critical to keeping our astronauts safe while they live and work on the surface of Mars.

Manufacturing in Space. The infrastructure build out needed for a human mission to Mars, especially for when our astronauts reach Martian soil is a complex and complicated challenge. NASA has worked with America Makes—the Manufacturing USA institute focused on additive manufacturing—to hold a competition for 3D printing of habitats using indigenous materials. An alternate approach to indigenous materials would be to pre-place materials and equipment on Mars, but that may take some technology development for landing of heavy payloads.

Question. What do you think is the most likely solution for manufacturing on Mars and how much is being invested in this area right now?

Answer. Today we are seeing increased commercial interest in in-space manufacturing, particularly in CisLunar space. In fact, ULA is working with NASA and oth-

ers in industry to provide the launch services necessary to facilitate these activities. Translating what we learn about in-space manufacturing to our operations on Mars will help us reduce the cost of getting supplies to the Martian surface. Having said that, there will be materials, supplies, and hardware that are just too complex to manufacture on the surface. That is where the capability provided by SLS and Orion will be critical, by providing large-scale transportation services to the surface. Smaller, EELV-class rockets such as Atlas V, Delta IV, and Vulcan can be used to send smaller packages in advance of a human landing as well.

Gateway. The Orbital Gateway will certainly be an important component in deep space exploration, but there is still some uncertainty about its specific functions.

Question 1. How is the Orbital Gateway specifically being designed to enable future exploration of Mars? For example, will it serve to address major technology needs like long-term life support, will it provide infrastructure for communication and in situ resource utilization at Mars? Or will it function more to service missions to the Moon?

Answer. I defer specific questions on Orbital Gateway architecture to NASA. Broadly speaking, I believe it is possible to utilize the Gateway for deep space (such as Mars exploration missions) as well as help facilitate human landings on the lunar surface and commercial missions in CisLunar space, the latter being the types of missions ULA is already leading on.

Question 2. What timeline is expected or necessary for development of the Gateway to support the exploration of Mars?

Answer. I defer to NASA on the timeline for the Gateway.

Technology Development. One of the reasons given for pursuing bold exploration missions is that the technology developed to enable the mission transfers to the commercial sector and improve the everyday lives of people right here on Earth.

Question. In prioritizing putting humans on Mars, what sorts of unique technologies will be developed that might benefit everyday life that would not be realized if we concentrate only on additional work in low Earth orbit or other missions to the Moon?

Answer. We may not yet know what those technologies will look like, but our experience shows us that advancements in space lead to improved quality of life here on Earth. Ultra-lightweight materials will be necessary to maximize the load astronauts will be able to take with them to Mars. Additionally, as my colleague Dr. Newman stated in her testimony, medical, biological and genetic advancements will be necessary as well, particularly when it comes to combatting radiation both in space and on the surface of Mars.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. GARY PETERS TO
CHRIS CARBERRY

International Cooperation. The U.S. will likely not be alone in our quest to put humans on Mars. With more potential international partners now growing space programs than ever before, putting together a coordinated effort will be challenging. As administrations change, so do our priorities in space, making it difficult for our potential partners to be assured of long-term plans.

Question. What sort of plans or agreements would be helpful in building a coordinated international coalition for a mission to Mars?

Answer. The United States needs to make a clear and unequivocal commitment to send humans to Mars within the next two decades. Our international partners have repeatedly looked to the United States for leadership, but due to our indecisiveness they have not been confident that the U.S. will fully follow through with the goals (particularly Mars) that we have advocated. The U.S. should engage the ISS partnership and start planning collaborative missions to deep space. With a clear goal, a specific timeline, and meaningful ways in which our partners can contribute to these missions, we can begin a new long-term international partnership that leads us to Mars.

Sample Return. A recent article published in the journal *Science* announced the discovery of organic molecules in ancient Martian rocks. These were the results of data coming from the Curiosity rover. Just think how much more could be realized with in-depth studies in laboratories here on Earth. The Decadal Survey for Planetary Science covering 2013 to 2023 states the start of a sample return mission from Mars should be the highest priority mission for NASA. Yet we still have no firm commitment to the Mars Sample Return mission in the FY19 budget.

Question 1. When will we need a commitment or specific plans for sample return to maintain leadership in this area?

Answer. Sample return is the first priority of the Planetary Science Decadal Survey—and is an extremely important precursor mission in our efforts to advance human exploration. A commitment should be made within the next year to assure that the mission can fly in the mid-2020s. As suggested in the *Mars Achievability and Sustainability Workshops* (<https://www.exploremars.org/affording-mars>), NASA and its partners should consider a ‘heavy’ sample return mission that will not only bring back a significant amount of Martian samples, but will also serve as a preliminary test of Entry, Descent, and Landing techniques and other vital technologies.

Question 2. Should we prioritize a multi-mission effort targeting the return of large Martian samples to Earth sooner rather than later, or would this be to the detriment of getting humans on Mars?

Answer. While Mars Sample Return (MSR) is an important precursor before sending humans to Mars, it should serve to feed forward and/or accelerate human missions and must not result in delaying human missions. As mentioned above, if this mission can be consolidated into an approach that brings back large amounts of samples *and* advances important capabilities required for human landings, we could accomplish multiple priorities simultaneously. If MSR is divided into multiple missions, these missions should be designed in a way to satisfy multiple requirements for human missions [such as bolster communications, perform In-Situ Resource Utilization (ISRU) tests, provide reconnaissance, etc.].

Manufacturing in Space. The infrastructure build out needed for a human mission to Mars, especially for when our astronauts reach Martian soil is a complex and complicated challenge. NASA has worked with America Makes—the Manufacturing USA institute focused on additive manufacturing—to hold a competition for 3D printing of habitats using indigenous materials. An alternate approach to indigenous materials would be to pre-place materials and equipment on Mars, but that may take some technology development for landing of heavy payloads.

Question. What do you think is the most likely solution for manufacturing on Mars and how much is being invested in this area right now?

Answer. Because we can not be certain of the availability of resources in a specific location until we actually go there, the first missions on Mars should not *rely* on these technologies, but if possible, initial experimentation should be undertaken to test the viability of utilizing indigenous resources. If initial tests are successful, we expect that future missions will build greater and greater reliance on in-situ resources. Also, in addition to technologies like the 3D printing technologies mentioned above, we will need to learn how to utilize the soil for other potential building materials (bricks) and to grow crops. Utilization of the water and the CO₂ atmosphere will also be essential in the manufacturing of oxygen, methane fuel, and of course water that is consumable, but can be used in other processes as well.

Gateway. The Orbital Gateway will certainly be an important component in deep space exploration, but there is still some uncertainty about its specific functions.

Question 1. How is the Orbital Gateway specifically being designed to enable future exploration of Mars? For example, will it serve to address major technology needs like long-term life support, will it provide infrastructure for communication and in situ resource utilization at Mars? Or will it function more to service missions to the Moon?

Answer. The Gateway must be designed and utilized in a manner that advances critical capabilities/technologies needed for Mars. It must *not*, however, in an era of limited budgets, be treated as a new destination or replacement for the ISS. It must therefore not be larger than needed to serve as support infrastructure for missions to Mars. While we hope that this facility can also be used to stimulate international and commercial lunar activities, more design work needs to be done to assure that this facility will be an asset to human Mars exploration and not a hindrance.

Question 2. What timeline is expected or necessary for development of the Gateway to support the exploration of Mars?

Answer. This depends on our target date for human landings on Mars. If we are still committed to sending humans to Mars by the early to mid-2030s (which Explore Mars, Inc. has supported for many years and Congress in the *NASA Authorization Act of 2017* fully supported), the Gateway should be operational by 2023–2025.

Technology Development. One of the reasons given for pursuing bold exploration missions is that the technology developed to enable the mission transfers to the commercial sector and improve the everyday lives of people right here on Earth.

Question. In prioritizing putting humans on Mars, what sorts of unique technologies will be developed that might benefit everyday life that would not be realized if we concentrate only on additional work in low Earth orbit or other missions to the Moon?

Answer. While it is difficult to predict the precise benefits of future space missions, we know from past experience that benefits from our space program improve life on Earth in substantial and profound ways. Mars is unique in that it provides the most promising environment to fully advance these capabilities. For example, in order to establish a long-term presence on Mars, we will need to learn how to perfect agriculture on that planet—probably utilizing Martian soil. Learning to grow crops in this comparatively arid (and potentially toxic) soil should result in untold benefits to Earth agriculture. Water extraction, purification, and conservation techniques will also be vital on Mars and can benefit Earth. In contrast, due to the proximity of the Moon to the Earth, astronauts in the vicinity of the Moon will be able to be resupplied from Earth. On Mars, however, astronauts will need to utilize technologies and capabilities that are self-sufficient, including advanced 3D printing, more advanced life support and environmental controls, and other systems. New technologies for deep space communications that are necessary for Mars could also prove to provide substantial benefits to people back on Earth.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. BILL NELSON TO
DR. DAVA J. NEWMAN

Question. The administration has proposed a new lunar exploration program, including a space station in lunar orbit and a series of lunar landers, progressing to a human-rated lander in the late 2020s. What direction should Congress provide to ensure lunar exploration missions most effectively advance a human Mars mission?

Answer. Phase II of NASA's three phase plan to get humans to Mars in the 2030s is a necessary and logical next step, now known as the 'Lunar Gateway'. Investments in deep space should focus on technology advancements necessary for putting humans on Mars, which include heavy lift launch capability, solar electric propulsion (for cargo), smart space habitats (including autonomy and mobility), advanced life support and space suit systems, and radiation protection. However, there should be no lunar/Gateway 'dead-end element' investments, meaning technologies that do not further both lunar and Mars exploration. Sending astronauts into deep space and to the lunar surface is valuable to test all the relevant systems, further explore the lunar surface, adopt new ConOps (scientific and exploration concept of operations), and to investigate astronaut performance for long-duration (>1 year) are all essential aspects of human exploration.

As long as we keep our focus on the horizon goal—boots on Mars—and do not overcommit human exploration resources solely to return humans to the lunar surface again, using cis-lunar space to develop the needed infrastructure like the lunar orbital platform gateway are prudent investments. But let's remember that the lunar programs should be in service, an actual stepping stone rather than an anchor, to human missions to Mars. The Moon is an interim destination, not the end goal. With constrained budgets, we cannot afford to solely fund lunar orbital and surface missions without making sure NASA has a balanced exploration portfolio including low earth orbit, deep space (lunar), and Mars. Congress should keep a close eye on NASA's deep space mission progress and apply pressure and provide sufficient funding to keep NASA focused on Mars. I support the Sense of Congress in the 2017 NASA Authorization Act to develop a human exploration roadmap.

In our MIT-authored American Academy of Arts and Sciences (AAAS) report, "*The Future of Human Space Flight: Objectives and Policy Implications in a Global Context*" (D. Mindell, *et al.*, 2009, pp. 59–62) we discussed the pros and cons of going to the Moon in service to a human Mars mission. I find the fundamental concepts to remain true: "If the Nation's goal is to proceed quickly to Mars, NASA should plan for a more minimalist campaign on the Moon using systems that are to the maximum extent designed for human Mars missions." NASA has not demonstrated a 'minimalist' approach in any human spaceflight endeavor (*e.g.*, Apollo, Space Shuttle, ISS, SLS) thus far, therefore, innovative organizational structures/functions, revolutionary technology, and public-private partnerships, and novel international partnerships are all necessary for a robust, integrated human-scientific-technology driven exploration roadmap (Wood and Newman, IAC, 2016).

From NASA: <https://www.nasa.gov/feature/nasa-to-return-humans-to-the-moon>

NASA Moon to Mars overview: <https://www.nasa.gov/topics/Moon-to-mars/overview>

Mindell, D.A., Uebelhart, S.A., Siddiqi, A.A., and Gerovitch, S. *"The Future of Human Space Flight: Objectives and Policy Implications in a Global Context"*, AAAS, 2009, pp. 59–62, <https://www.amacad.org/publications/spaceFuture.pdf>

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RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. GARY PETERS TO
DR. DAVA J. NEWMAN

International Cooperation. The U.S. will likely not be alone in our quest to put humans on Mars. With more potential international partners now growing space programs than ever before, putting together a coordinated effort will be challenging. As administrations change, so do our priorities in space, making it difficult for our potential partners to be assured of long-term plans.

Question. What sort of plans or agreements would be helpful in building a coordinated international coalition for a mission to Mars?

Answer. Getting humans on Mars is an ambitious goal and it will require global cooperation, especially on the timeline I envision. I believe that the U.S. and NASA should be a leader in such a coalition, but our most impactful journey to Mars requires that we capitalize on the strengths of our international partners. Effective collaboration and partnering means prioritizing and negotiating the most efficient and effective distribution of responsibility for every major element of the mission to Mars from launch, through orbit, to landing, surface stays, to ascent and return to Earth. Scientists and engineers are used to this type of global collaboration—at NASA especially, which has more than 700 active international agreements with over 120 nations bringing a multitude of benefits to NASA, the U.S. and all international partners.

The mission's technology and scientific needs should drive the strategy, although, we have to be simultaneously sensitive to international politics and global competitiveness in any such agreement. I believe the best example of 'soft diplomacy' between the USA and Russia is the International Space Station and our close cooperation in human spaceflight between the U.S. and Russia since Apollo-Soyuz, over 40 years ago. The majority of NASA's international partnerships are with 8 countries, namely, France, Germany, ESA (European Space Agency—23 nations), Japan, United Kingdom, Italy, Canada, and Russia. We can learn from the International Space Station. The ISS is a model of success in global cooperation. With five main space agency partners and about 100 countries using the ISS, we already have a blueprint for successful international space partnerships. Likewise, the Mars 2020 Rover is a collaborative effort with instrumentation from the U.S. as well as several international partners providing scientific instruments.

By taking a leading role in such partnerships, and implementing a 'distributed leadership model' our Nation will glean the benefits of working on and developing new technologies in pursuit of the mission, including but not limited to high-skilled workforce development, inspiring the next generation of STEM professionals, and economic development through technology transfer spinoffs. At the same time, the U.S. must give sufficient leadership and partnership opportunities to our international partners for their respective contributions if we hope to realize significant global cooperation in space science and exploration missions.

As you noted, when administrations change it can be challenging to maintain priorities and stay the course, which is why we need Congress to keep the U.S. focused on Mars as the horizon goal for human spaceflight, informed by career staff at NASA with technical expertise. I support the sense of Congress in the 2017 NASA Authorization Act to develop a human exploration roadmap that would include a plan for international partnerships to accelerate the journey to Mars, which should necessarily include significant contributions from partners for lunar missions, capabilities and infrastructure. To achieve the goal of putting humans on Mars, Congress must provide resources commensurate with expectations.

Further discussion on global partnerships for a human mission to Mars are noted in our AAAS report on pp. 64–66., "Although the balance between cooperation and competition with other nations in human spaceflight remains dependent on larger foreign policy issues, human spaceflight provides an effective diplomatic tool for the United States to use to further the primary objective of global leadership."

NASA Office of Interagency and International Relations, https://www.nasa.gov/sites/default/files/atoms/files/oirr_international_tag.pdf

Mindell, D.A., Uebelhart, S.A., Siddiqi, A.A., and Gerovitch, S. “*The Future of Human Space Flight: Objectives and Policy Implications in a Global Context*”, AAAS, 2009, pp. 64–66. <https://www.amacad.org/publications/spaceFuture.pdf>

Dr. Dava Newman, speech to the Council on Foreign Relations, Oct. 2016: https://www.nasa.gov/sites/default/files/atoms/files/161006_newman_final_cfr.pdf pg 5

Sample Return. A recent article published in the journal *Science* announced the discovery of organic molecules in ancient Martian rocks. These were the results of data coming from the Curiosity rover. Just think how much more could be realized with in-depth studies in laboratories here on Earth. The Decadal Survey for Planetary Science covering 2013 to 2023 states the start of a sample return mission from Mars should be the highest priority mission for NASA. Yet we still have no firm commitment to the Mars Sample Return mission in the FY19 budget.

Question 1. When will we need a commitment or specific plans for sample return to maintain leadership in this area?

Answer. We need specific plans and a commitment for a sample return in the 2020s as soon as possible. Several other countries (ESA, China, possibly Russia, India, and UAE) are looking to develop Mars sample return missions. So far, they have not developed past the study phase. All are interested in partnering with NASA and the US.

Question 2. Should we prioritize a multi-mission effort targeting the return of large Martian samples to Earth sooner rather than later, or would this be to the detriment of getting humans on Mars?

Answer. There are always trade-offs within the constrained NASA budget. Among many competing priorities, you have to make tough choices. I agree that sample return has great scientific potential and should be a high priority. I also recommend an integrated Mars Program Office, which combines resources and expertise from the now separate SMD, HEOMD, and STMD. Additionally, Mars sample return could provide information that would benefit and perhaps accelerate the mission to put humans on Mars, such as development of the Mars Ascent Vehicle (MAV). Development of MAV would likely serve as a smaller test bed for developing a larger ascent vehicle needed for human missions, *i.e.*, returning humans to space from the surface of Mars. It is also possible that what we learn about the soil on Mars through MSR will inform our manufacturing, food production, and in-situ resource utilization (ISRU) strategies for human missions.

Manufacturing in Space. The infrastructure build out needed for a human mission to Mars, especially for when our astronauts reach Martian soil is a complex and complicated challenge. NASA has worked with America Makes—the Manufacturing USA institute focused on additive manufacturing—to hold a competition for 3D printing of habitats using indigenous materials. An alternate approach to indigenous materials would be to pre-place materials and equipment on Mars, but that may take some technology development for landing of heavy payloads.

Question. What do you think is the most likely solution for manufacturing on Mars and how much is being invested in this area right now?

Answer. On Mars, we will need a “maker” to manufacture a lot of the materials for life support and exploration. I give my MIT students the challenge to “make the maker on Mars”—a true replicator capability from indigenous resources coupled with what we can manage to ship to Mars. We will be extremely weight limited on our journey to Mars. All successful exploration throughout human history teaches us that ‘living off the land/ocean’ is an essential capability. Unsuccessful exploration teaches us the opposite, that you can’t bring it all with us.

In any case, we must develop the capabilities of landing much heavier payloads on Mars than we ever have in the past. We currently know how to land one or two metric tons on Mars, but it will be necessary to land 10 to 20 metric tons needed for a human mission to the Red Planet, regardless of the manufacturing capabilities we can reap from Martian resources. My numbers of 10–20 metric tons are much less than NASA’s current estimates of 20–40 metric tons for a human mission, however, I believe that advances in manufacturing, ISRU, and incorporating flexibility and modularity in to engineering systems design allows for a realistic reduction in payload and mission mass.

To answer your question, I believe we will need *both* heavy-payload landing technologies and on-site manufacturing on Mars. I do not have specific numbers on the current NASA investments in deep space manufacturing, but the numbers are very small/minimum for the low technology readiness level (TRL) investments, well below what they should be for an adequate technology investment strategy and portfolio. I also recommend that NASA should team and partner with the substantial advanced manufacturing efforts that the DOD and NSF are currently funding.

Dr. Dava Newman, speech at the World Economic Forum, Aug. 2016: <https://www.youtube.com/watch?v=MM4iLPWl5zc>

Gateway. The Orbital Gateway will certainly be an important component in deep space exploration, but there is still some uncertainty about its specific functions.

Question 1. How is the Orbital Gateway specifically being designed to enable future exploration of Mars? For example, will it serve to address major technology needs like long-term life support, will it provide infrastructure for communication and in situ resource utilization at Mars? Or will it function more to service missions to the Moon?

Answer. Phase II of NASA's three phase plan to get humans to Mars in the 2030s is a necessary and logical next step, now known as the 'Lunar Gateway'. I share your concern that the Orbital Gateway is not currently focused on critical technology innovation and needs, such as advanced long-term, autonomous life support systems, advanced state-of-the-art communications (*i.e.*, laser COMM), and ISRU testbeds and demonstrations for Mars. Investments in deep space should focus on technology advancements necessary for putting humans on Mars, which include heavy lift launch capability, solar electric propulsion (for cargo), smart space habitats (including autonomy and mobility), advanced life support and space suit systems, and radiation protection. There should be no lunar/Gateway 'dead-end element' investments, meaning existing habitat and life support system technologies that 'do not closed the loop' and that do not further both lunar and Mars exploration. Sending astronauts into deep space and to the lunar surface is valuable to test all the relevant systems, further explore the lunar surface, adopt new ConOps (scientific and exploration concept of operations), and to investigate astronaut performance for long-duration (>1 year) are all essential aspects of human exploration.

I do not have specific insights into the functionality of the Lunar Orbital Platform Gateway, since it was proposed after my tenure at NASA, but I can say that we will need some type of infrastructure as a test bed for long term life support systems and other technologies we have yet to fully develop. It is important that Congress maintain pressure on such cis-lunar missions to keep the focus on the technological breakthroughs necessary to succeed in future human missions to Mars utilizing advanced technologies. At the same time, Congress should provide resources that match expectations to avoid asking too much of NASA with too little means.

In our MIT-authored American Academy of Arts and Sciences (AAAS) report, "*The Future of Human Space Flight: Objectives and Policy Implications in a Global Context*" (D. Mindell, *et al.*, 2009, pp. 59–62) we discussed the pros and cons of going to the Moon in service to a human Mars mission. I find the fundamental concepts to remain true: "If the Nation's goal is to proceed quickly to Mars, NASA should plan for a more minimalist campaign on the Moon using systems that are to the maximum extent designed for human Mars missions." NASA has not demonstrated a 'minimalist' approach in any human spaceflight endeavor (*e.g.*, Apollo, Space Shuttle, ISS, SLS) thus far, therefore, innovative organizational structures/functions, revolutionary technology, and public-private partnerships, and novel international partnerships are all necessary for a robust, integrated human-scientific-technology driven exploration roadmap (Wood and Newman, IAC, 2016).

Mindell, D.A., Uebelhart, S.A., Siddiqi, A.A., and Gerovitch, S. "*The Future of Human Space Flight: Objectives and Policy Implications in a Global Context*", AAAS, 2009, pp. 59–62, <https://www.amacad.org/publications/spaceFuture.pdf>

Wood, D. and Newman, D. "The Innovation Landscape within a Large Government Agency: Promising Practices from the U.S. National Aeronautics and Space Administration (NASA)", International Astronautical Congress, Guadalajara, Mexico, Sept. 2016.

Question 2. What timeline is expected or necessary for development of the Gateway to support the exploration of Mars?

Answer. The 2030s are in our immediate future when it comes to spaceflight systems and qualification, so we must proceed urgently with haste to meet our goal of human missions to Mars within that decade. According to NASA, they plan to "develop the Lunar Orbital Platform-Gateway that emplaces a power-propulsion (communications) element (PPE) around the Moon by 2022." This is one of the first steps needed to establish the lunar orbiting platform for future astronauts to depart to and return from Mars. Many steps are needed between this milestone, targeted for 2022, and putting people on Mars in the 2030s, so there is no time to waste. I believe that "constancy of purpose" must be exercised and implemented from leadership on down.

NASA <https://www.nasa.gov/topics/moon-to-mars/overview>

Technology Development. One of the reasons given for pursuing bold exploration missions is that the technology developed to enable the mission transfers to the commercial sector and improve the everyday lives of people right here on Earth.

Question. In prioritizing putting humans on Mars, what sorts of unique technologies will be developed that might benefit everyday life that would not be realized if we concentrate only on additional work in low Earth orbit or other missions to the Moon?

Answer. Advanced life support systems, space suits, mobility systems, and advanced autonomy immediately come to mind and will undoubtedly have spinoffs for human health on Earth. Already we are seeing potential applications of the space suits we have designed that could act as soft exoskeletons for patients with muscular-skeletal diseases. My tunable joint stiffness patents designed for astronauts spending months and years in space could provide extra relief and maybe even technological solutions to mobility issues in the elderly and humans crippled by disease or accidents on Earth. Of the hundreds of NASA spin-off technologies per year, water filtration technology and portable, hand-held ultrasound are two of my favorite ISS technology spin-offs.

Fully autonomous spacecraft, habitats, and systems needed for Mars, will require new technologies to entirely close the air loops and water loops so that all the resources on the spacecraft are fully recycled. These environmental closed life support systems (ECLSS) recycling technologies have important applications for water conservation on Earth, energy-efficient indoor air quality systems in buildings, and human survival in extreme environments on Earth or in special circumstances like extended tours on submarines etc. I also cite advanced materials, wearable sensors, and novel actuators needed for human travel to Mars as having dual use applications for products back on Earth.

Some of the technology spinoffs are not predictable. Many of NASA's past spinoffs spur from technologies that were not expected to have an application for everyday life on Earth, yet they consistently deliver such outcomes. More examples can be found at: <https://spinoff.nasa.gov/>.

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