AN OVERVIEW OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION BUDGET FOR FISCAL YEAR 2018

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED FIFTEENTH CONGRESS

FIRST SESSION

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June 8, 2017

AN OVERVIEW OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION BUDGET FOR FISCAL YEAR 2018

THURSDAY, JUNE 8, 2017

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

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

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

Congress of the United States
House of Representatives
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
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An Overview of the National Aeronautics and Space Administration Budget for Fiscal Year 2018

Thursday, June 8, 2017
10:00 a.m.
2318 Rayburn House Office Building

Witness

Mr. Robert M. Lightfoot, Jr., Acting Administrator, National Aeronautics and Space Administration (NASA)

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

Charter

TO:	Members, Committee on Science, Space, and Technology
FROM:	Majority Staff, Committee on Science, Space, and Technology
DATE:	June 8, 2017
SUBJECT:	Space Subcommittee Hearing: "An Overview of the National Aeronautics and Space Administration Budget for Fiscal Year 2018"

On Thursday, June 8, 2017 at 10:00 a.m. in Room 2318 of the Rayburn House Office Building, the Committee on Science, Space, and Technology, Subcommittee on Space will hold a hearing titled, "An Overview of the National Aeronautics and Space Administration Budget for Fiscal Year 2018."

Hearing Purpose

The purpose of the hearing is to review the Administration's fiscal year 2018 (FY18) budget request for the National Aeronautics and Space Administration (NASA).

Witness

- **Mr. Robert M. Lightfoot, Jr.**, Acting Administrator, National Aeronautics and Space Administration (NASA)

Staff Contact

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

Chairman BABIN. The Subcommittee on Space will come to order. And without objection, the Chair is authorized to declare recesses of the Subcommittee at any time.

Welcome to today's haring entitled "An Overview of the National Aeronautics and Space Administration Budget for Fiscal Year 2018." I now recognize myself for five minutes for an opening statement.

NASA is a critical national investment in our future. Our nation has never faced a more challenging, relevant, or promising frontier than the vast reaches of outer space. I am very proud that this Committee clearly recognizes and demonstrates that U.S. leadership in space is a bipartisan priority.

The recent passage and enactment of the 2017 NASA Transition Authorization Act this March is concrete proof of the bipartisan and bicameral commitment to NASA. This budget reflects the Administration's commitment to the continuity of purpose described in the recent authorization. Honoring our commitments in space and maintaining a balanced portfolio are the surest ways for us to enjoy the full benefits of our space investments.

The numbers in this request are lower than the amounts in the enacted budget, which causes some concern. However, the preliminary budget blueprint was released before Congressional appropriations. Therefore, the lower request does not necessarily reflect a reduction in Administration support for NASA. In fact, the current request is in line with recent levels appropriated by Congress. This goes a long way to fixing problems that have plagued NASA programs over the last eight years. This budget request is refreshing in that it does not propose slashing priority programs year after year. This will allow NASA managers to execute programs in an efficient manner.

I want to reiterate the Committee's commitment to NASA's long-term goals, as described in law. Mars remains the first interplanetary destination for humanity. NASA is encouraged to carry out any necessary intermediate missions, particularly to the Moon, provided that those missions advance future interplanetary exploration.

Closer to home, the future of the International Space Station is a top concern. Currently, the ISS will operate until 2024, but the role of the ISS beyond 2024 must be addressed soon. Similarly, I am also interested in understanding what NASA's plans are for future space suit work.

Turning to NASA's scientific exploration, this budget request restores balance across NASA's science portfolio and supports critical work across the entire science directorate. Work continues on the James Webb Space Telescope, which I am very proud to say is currently in our home district at the Johnson Space Center for testing where I was yesterday, along with Acting Administrator Lightfoot and our Chairman of the main Science Committee, I'm very proud to say, along with the Vice President of the United States, meeting our 12 new astronauts of class 2017.

But back to the budget. The budget supports a range of small, medium, and large science missions, including the flagship Europa Clipper and Mars 2020 rover missions. During the Obama Administration, the pipeline for outer-planet missions was allowed to run

dry. This budget returns support for a robust planetary exploration program, which is a national priority. U.S. leadership in space science is critical in part because it supports so much of NASA's broader mission.

Under this budget, NASA Aeronautics will continue its work on innovative technologies, including a low boom supersonic flight demonstrator and hypersonic flight. These programs continue to benefit our civil and military aeronautics efforts.

NASA's work in the Space Technology Mission Directorate will be critical in future space exploration. Work on space technologies like laser communication, in-space propulsion, and power systems will allow human exploration to complement the robotic exploration of Mars and other celestial bodies.

NASA has many exciting projects and missions across its portfolio. Indeed, NASA may be on the threshold of one of the greatest inflection points in the history of space exploration. Soon, SLS, Orion, Dragon 2, and Starliner vehicles will take their first flights. The James Webb Space Telescope will see its first light. Human presence in low-Earth orbit is maturing, and the ISS will begin evolving to the next phase of its life. And soon, NASA will begin construction of the Deep Space Gateway, the first permanent human outpost beyond low-Earth orbit. Of course, this era of excitement will also be a time of high risk. But with Congressional and Administration budgetary and political support, the next decade could very well mark a new golden age of space exploration. And I want to thank Acting Administrator Lightfoot for his testimony and look forward to his discussion.

[The prepared statement of Chairman Babin follows:]

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

For Immediate Release
June 08, 2017

Media Contact: Kristina Baum
(202) 225-6371

Statement of Space Subcommittee Chairman Brian Babin (R-Texas)
An Overview of the National Aeronautics and Space Administration Budget for Fiscal Year 2018

Chairman Babin: NASA is a critical national investment in our future. Our nation has never faced a more challenging, relevant, or promising frontier than the vast reaches of outer space.

I am proud that this Committee clearly recognizes and demonstrates that U.S. leadership in space is a bipartisan priority. The recent passage and enactment of the 2017 NASA Transition Authorization Act this March is concrete proof of the bipartisan and bicameral commitment to NASA.

This budget reflects Administration's commitment to the "continuity of purpose" described in the recent authorization. Honoring our commitments in space and maintaining a balanced portfolio are the surest ways for us to enjoy the full benefits of our space investments.

The numbers in this request are lower than the amounts in the enacted budget, which causes some concern. However, the preliminary budget blueprint was released before Congressional appropriations. Therefore, a lower request does not necessarily reflect a reduction in Administration support for NASA. In fact, the current request is in line with recent levels appropriated by Congress. This goes a long way to fixing problems that have plagued NASA programs over the last eight years. This budget request is refreshing in that it does not propose slashing priority programs year-after year. This will allow NASA managers to execute programs in an efficient manner.

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During the Obama Administration, the pipeline for outer-planet missions was allowed to run dry. This budget returns support for a robust planetary exploration program, which is a national priority. US leadership in space science is critical, in part because it supports so much of NASA's broader mission.

Under this budget, NASA Aeronautics will continue its work on innovative technologies including a low boom supersonic flight demonstrator and hypersonic flight. These programs continue to benefit our civil and military aeronautics efforts.

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NASA has many exciting projects and missions across its portfolio. Indeed, NASA may be on the threshold of one of the greatest inflection points in the history of space exploration. Soon, SLS, Orion, Dragon 2, and Starliner vehicles will take their first flights. The James Webb Space Telescope will see first light. Human presence in low-Earth orbit is maturing and the ISS will begin evolving to the next phase of its life. And soon, NASA will begin construction of the Deep Space Gateway, the first permanent human outpost beyond low-Earth orbit. Of course, this era of excitement will also be a time of high risk. But with Congressional and Administration budgetary and political support, the next decade could mark a new golden age of space exploration.

I thank Acting Administrator Lightfoot for his testimony and look forward to this discussion.

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Chairman BABIN. And now, I'd like to recognize the Ranking Member, the gentleman from California, Mr. Bera, for an opening statement.

Mr. BERA. Thank you, Mr. Chairman.

Good morning. Welcome to Acting Administrator Lightfoot, and thank you for your dedicated service to NASA over the many years.

The fiscal year 2018 proposal for NASA is $19.1 billion, a nearly three percent reduction from last year's fiscal year budget. And, in the context of the overall federal budget, you know, $19 billion does suggest a recognition of the importance of NASA and, you know, both from the Administration perspective as well as ours. But there are a few things that give me pause when I look at the detail of the budget.

Part of our goal—being a child of the space race—is education and inspiring that next generation, and one thing that I do worry about is the cut in the education budget, and I certainly want to hear from Administrator Lightfoot how we might go about continuing to inspire that next generation, our children, and that next generation of astronauts, especially in such a vibrant, exciting time with regards to space, when we think about the multiple missions, when we think about human space travel potentially to Mars and back again, when we think about the existential questions like the search for life, are we alone, and what does that look like the rapidity by which we are discovering planets that potentially could house life.

The Chairman talked about the missions going to deeper space. I thought the second half of the 20th century was a super exciting time for space, but I truly believe the coming decades are going to be much more exciting. You're seeing the rapid entry of the private sector into space, the commercialization of space, the amount of venture money that's going into space. And I truly believe that this has the ability of inspiring the next generation of scientists, of engineers, et cetera, as they see that, and I want to make sure we continue that.

There is about a nine percent cut to NASA's exploration budget. That does give me a little bit of pause as well, again, at a time where I think we've got to continue U.S. leadership in space. Space in the 21st century will be an international endeavor, as other countries get engaged. That said, I still think U.S. leadership and American ingenuity with regards to space is going to be incredibly important.

The last thing is, as we look at the multiple missions, what we discover in space also helps us understand our own planet much better and Earth, and I do want to make sure that the Earth sciences mission is also protected. NASA obviously has a critical role in the Earth sciences mission, and I certainly want to hear from the Acting Administrator.

That said, NASA is a source for many of us of national pride. It is certainly something that, you know, we think leads the way. And I think NASA also, as we look at international diplomacy, how we work with other countries around the world, space, and the International Space Station is a model example of how the world can work together, especially as these discoveries are not just for the United States, they're for all of humanity.

So with that, I look forward to hearing from Mr. Lightfoot, and I'll yield back.

[The prepared statement of Mr. Bera follows:]

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

House Committee on Science, Space, and Technology
Subcommittee on Space
"An Overview of the National Aeronautics and Space Administration Budget for Fiscal Year 2018"
June 8, 2017

Good morning. Welcome Acting Administrator Lightfoot and thank you for your dedicated service to NASA over many years.

The Fiscal Year (FY) 2018 budget proposal for NASA is about $19.1 billion, a nearly 3% reduction from the FY 2017 enacted appropriation.

Mr. Chairman, I recognize these are difficult times, and in the context of the overall proposed federal budget, $19 billion can be seen as a recognition of the important role NASA plays. However, when looking below the surface of this budget request, some of the details give me pause.

While the request proposes $5.7 billion for NASA's Science Mission Directorate, it does so while terminating five Earth science missions. I am concerned about what this cut says about our stewardship of Earth and the legacy we want to leave behind for our children and grandchildren.

Speaking of children, Mr. Chairman, the FY 2018 proposal seems to forget the next generation. NASA has served as a catalyst for inspiring our Nation's youth to pursue science, technology, engineering, and math education and careers. However, this budget request would eliminate NASA's Office of Education and funding for cornerstone programs such as Space Grant, the Established Program to Stimulate Competitive Research (EPSCoR), and the Minority University Research and Education Project (MUREP).

We need the next generation to be energized and prepared for the exciting goals we are asking NASA to achieve, including sending humans to Mars. Unfortunately, a 9% cut to NASA's exploration programs—including the key systems that will enable the United States to return to deep space—does not help get us closer to Mars or build on the inspiration and curiosity of the next generation. Nor does it mirror Congress' intent when it provided an increase of nearly $400 million to NASA for FY 2017 over the FY 2016 enacted level. Or when it passed the NASA Transition Authorization Act to provide stability for NASA programs.

Mr. Chairman, this body and the Administration need to be on the same page to enable the

"constancy of purpose" that NASA needs to meet the challenging tasks the Nation has given it. Unfortunately, the budget proposed for Fiscal Year 2018 will set NASA back. By flat- funding NASA in the out years, NASA's purchasing power would actually shrink by a total of about $4.5 billion over the 5-year budget horizon.

It's up to us on this Committee and in this body to provide the resources NASA needs to stay on the cutting-edge of discovery in science, aeronautics, space technology, and human exploration.

NASA remains a critical national asset. For nearly 60 years, it has been a source of technological and scientific innovation, an inspiration to generations of Americans, and a driver for economic growth. Let us do what is necessary to keep NASA's future bright.

Thank you Mr. Chairman and I yield back.

Chairman BABIN. Thank you, Mr. Bera.

I now recognize the Chairman of our Full Committee, Mr. Smith from Texas.

Chairman SMITH. Thank you, Mr. Chairman. And welcome, Acting Administrator Lightfoot. As Chairman Babin said a minute ago, it was good to see you at Johnson Space Center yesterday. I'm still amazed that you got up here in time to be at this hearing today.

Mr. Chairman, this Committee has consistently demonstrated that U.S. leadership in space is a bipartisan priority. The 2017 NASA Transition Authorization Act, signed into law in March by President Trump, is a clear demonstration of that. A key concept in the current NASA Authorization is continuity of purpose. Over the years, erratic direction and changes in mission have repeatedly led our space exploration effort astray.

The fiscal year 2018 NASA budget shows that Congress and the Administration both support a consistent, focused space program. The amounts requested in this budget for not only the Space Launch System and Orion crew vehicle and the commercial crew and cargo programs reflect this. These requests are much closer to past appropriations and are realistic and reasonable, providing an increased level of stability and continuity of purpose for two of NASA's main initiatives.

This year's Authorization Act also declares that NASA's goals include extending human presence throughout the solar system. Accordingly, NASA continues to focus on Mars as its first interplanetary destination for human exploration. NASA should conduct missions to intermediate destinations on the way to Mars, such as the Moon, so long as those activities support subsequent journeys to Mars and beyond.

Previews of NASA's Deep Space Gateway program architecture have given us a peek at NASA's plans. We look forward to reviewing the Human Exploration Roadmap on how NASA plans to pursue its human space exploration goals in coming decades.

It's good to see that the NASA budget request ends the previous Administration's ill-conceived Asteroid Mission. The 2017 NASA Transition Authorization Act clearly reflects the concerns of both Congress and NASA's Advisory Council about the utility and cost-effectiveness of that mission. Instead, other and more needed technologies will be developed under different programs.

Likewise, within the Science Mission Directorate, the budget promotes a much better balance among NASA's many scientific endeavors, especially for planetary science. And it starts to reverse the significant growth in earth science. The Obama Administration's fiscal year 2017 earth science request was 42 percent higher than its request for planetary science, and that's 75 percent higher than the amount requested for earth science in 2007. As a reminder, there are many other federal agencies involved in earth science research, but only one agency that promotes space exploration. This budget reflects the idea that while NASA can continue to develop state-of-the-art Earth-sensing programs, it is not a piggy bank for funding climate activities already addressed elsewhere in the Federal Government.

The James Webb Space Telescope, which I saw under construction yesterday at Johnson Space Center, continues on budget and on schedule after NASA and Congress worked to correct for overruns and delays. We continue to expect a launch in October next year. NASA science supports other activities, too. The Transitioning Exoplanet Survey Satellite and the Wide Field Infrared Space Telescope will increase our understanding of exoplanets.

And I want to emphasize that the recent authorization bill directs NASA to, quote "search for life's origin, evolution, distribution, and future in the universe." The James Webb Telescope, Wide Field Telescope, and Exoplanet Survey Satellite will certainly advance this priority.

Congress has the responsibility for setting the top-level direction and missions for NASA and has done so with the 2017 NASA Transition Authorization Act. NASA is responsible for providing a compelling plan and executing it. Now that we have received the budget request, it is Congress' next responsibility to ensure NASA's budget is prioritized and funded. Of all the non-defense, non-security agencies in the Federal Government, NASA has received the most favorable proposed budget. And I am sure that this Committee will continue to support American leadership in space.

Thank you again, Mr. Chairman, and yield back.

[The prepared statement of Chairman Smith follows:]

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

For Immediate Release
June 08, 2017

Media Contact: Kristina Baum
(202) 225-6371

Statement of Chairman Lamar Smith (R-Texas)

An Overview of the National Aeronautics and Space Administration Budget for Fiscal Year 2018

Chairman Smith: Thank you, Chairman Babin. And welcome, Acting Administrator Lightfoot. It was good to be with you at Johnson Space Center (JSC) yesterday.

This Committee has consistently demonstrated that U.S. leadership in space is a bipartisan priority. The 2017 NASA Transition Authorization Act, signed into law in March by President Trump, is a clear demonstration of that.

A key concept in the current NASA Authorization is "continuity of purpose." Over the years, erratic direction and changes in mission have repeatedly led our space exploration effort astray. This fiscal year 2018 NASA budget shows that Congress and the Administration both support a consistent, focused space program.

The amounts requested in this budget for not only the Space Launch System and Orion crew vehicle but also for the commercial crew and cargo programs reflect this. These requests are much closer to past appropriations and are realistic and reasonable, providing an increased level of stability and continuity of purpose for two of NASA's main initiatives.

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Of all the non-defense, non-security agencies in the federal government, NASA has received the most favorable proposed budget. And I expect that this Committee will continue to support American leadership in space.

Thank you, Mr. Chairman, and I yield back.

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Chairman BABIN. Thank you, Mr. Chairman.

The Ranking Member of the full Committee is not here yet, so we're going to go on to introductions of our guests. Mr. Robert M. Lightfoot, Jr., our witness today, Acting Administrator of the National Aeronautics and Space Administration. His permanent title is Associate Administrator for NASA.

Before serving as Acting Administrator, Mr. Lightfoot was Director of NASA's Marshall Space Flight Center in Huntsville, Alabama, where he managed propulsion, scientific, and space transportation activities.

From 2003 to 2005, he served as Assistant Associate Administrator for the Space Shuttle Program at NASA's headquarters right here in Washington where he oversaw technical and budgetary oversight of the annual budget and initial transition and retirement efforts for the space shuttle infrastructure.

From 2005 to 2007, Mr. Lightfoot was responsible for overseeing the manufacture, assembly, and operation of the primary shuttle propulsion elements such as the main engines, solid rocket boosters, and reusable solid rocket motors.

Mr. Lightfoot received a bachelor's degree in mechanical engineering from the University of Alabama. He was also named distinguished departmental fellow from the University's Department of Mechanical Engineering in 2007 and was selected as a University of Alabama College of Engineering fellow in 2009.

And I would like to recognize Mr. Lightfoot for five minutes to present his testimony.

TESTIMONY OF ROBERT M. LIGHTFOOT, JR.,
ACTING ADMINISTRATOR,
NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION

Mr. LIGHTFOOT. All right. Thank you, Mr. Chairman. It's great to be here. I want to thank you and Chairman Smith for being in Houston yesterday. It was a very exciting event, and we appreciate your support——

Chairman BABIN. Absolutely.

Mr. LIGHTFOOT. —the team. Mr. Chairman and Members of the Committee, I'm pleased to have the opportunity to discuss NASA's fiscal year 2018 budget request. We appreciate the Committee's support and especially your bipartisan commitment to the constancy of purpose for NASA. The Transition Authorization Act for 2017 and the Consolidated Appropriations Act of 2017 are concrete contributions to this vital continuity, and we appreciate the Committee's hard work on NASA's behalf.

NASA's historic and enduring purpose can be summarized in three major strategic thrusts: discover, explore, and develop. These correspond to our missions of scientific discovery, missions of exploration, and missions of new technology development in aeronautics and space systems. NASA is focused on these missions, but we never lose sight of the other contributions that our unique achievements make possible. NASA's missions inspire the next generation. They inject innovation into the national economy, they provide critical infrastructure, information to national challenges, and they support global engagement and international leadership.

The fiscal year 2018 request of $19.1 billion supports a vigorous program that leads the world in space and aeronautics. And while we had to make some difficult decisions in regard to earth science and education, this remains a great budget for NASA.

With this budget, we will advance U.S. global leadership in aeronautics by developing and transferring key enabling technologies. In fiscal year 2018 we'll award a contract for detailed aircraft design, build, and validation of a low boom flight demonstrator. This low boom X-plane will demonstrate quiet overland supersonic flight, opening a new market to U.S. industry.

NASA will also use 20 spaceborne missions to study the Earth as a system. The request supports two new missions by the end of 2018, the GRACE Follow-On mission, which will track water across the planet by precisely measuring Earth's gravitational field; and ICESat-2, which will measure ice sheets, clouds, and vegetation canopy heights. We supply earth science data for weather forecasting, farming, water management, disaster response, and even disease early warning.

In September, Cassini will make a final series of 22 daring dives through the 1,500-mile-wide gap between the planet and its rings as part of its grand finale end-of-mission maneuvers. The OSIRIS–REx mission will conduct a search for elusive objects known as Earth trojan asteroids on its journey to the asteroid Bennu.

We'll also launch Mars InSight lander in 2018 to study the interior structure of Mars, and we're on track to launch the next Mars rover mission in 2020.

James Webb continues on schedule for its 2018 launch. That will be our next giant leap forward in our quest to understand the universe and our origins.

NASA's Transiting Exoplanet Survey Satellite or TESS will launch in 2018 as well, extending the pioneering discoveries of the Kepler Space Telescope.

In heliophysics, we'll also launch the recently named Parker Solar Probe on a mission to fly closer to the sun than any previous mission. That'll join 18 other missions that are dedicated to studying our closest star.

It's vital that NASA continues the investment in transformative space technology. In 2018, we'll continue to work in deep-space optical com, high-powered solar propulsion technologies, and advanced materials.

The International Space Station, our first step on the road to deep space exploration, is delivering the knowledge and technology we need to keep astronauts safe, healthy, and productive on deep space missions of increasing duration.

Working with our commercial crew partners, NASA plans on returning crew launch capability to American soil in 2018. We'll also continue the development of the SLS rocket, the Orion crew capsule and the ground systems, and the technologies and research needed to support and deploy critical life-support and habitation capabilities leading to crewed missions beyond the Earth-moon system.

In 2019, we'll plan a launch of the un-crewed Exploration Mission 1 using the new heavy lift launch vehicle SLS and Orion on

a mission to lunar orbit. Shortly after that, no later than 2023, we'll have a crewed mission of EM–2.

With your continued support, we look forward to extending human presence into deep space, exploring potential habitable environments around the solar system, and deepening our understanding of our home planet. We look forward to pushing our observations of the universe back to the time when the first stars were forming and opening the space frontier. While the future benefits of discovery are always difficult to predict, we are confident that the resources we are requesting represent an investment that will deliver significant return to the nation.

Mr. Chairman, I'd be pleased to respond to your questions and those of other members of the Committee. Thank you.

[The prepared statement of Mr. Lightfoot follows:]

HOLD FOR RELEASE
UNTIL PRESENTED
BY WITNESS
June 8, 2017

Statement of

Robert M. Lightfoot, Jr.
Acting Administrator
National Aeronautics and Space Administration

before the

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

Mr. Chairman and Members of the Committee, I am pleased to have this opportunity to discuss NASA's FY 2018 budget request. As the Agency approaches its 60th anniversary in 2018, the requested budget will maintain NASA's place as the global leader in space. We appreciate the Committee's support, and have been heartened by the frequently expressed bipartisan commitment to constancy of purpose for NASA, particularly as NASA's goals extend over decades. Beyond these expressions of support, the NASA Transition Authorization Act of 2017 and the FY 2017 Consolidated Appropriations Act represent concrete contributions to that continuity, and we appreciate the Committee's hard work on NASA's behalf. The FY 2018 budget request of $19.1 billion reflects the continuity of mission that is vital to our continued success.

NASA's historic and enduring purpose can be summarized in three major strategic thrusts: Discover, Explore, and Develop. These correspond to our missions of scientific discovery, missions of exploration, and missions of new technology development in aeronautics and space systems. NASA is focused on these missions, but we never lose sight of the other contributions that our unique achievements make possible. NASA missions inspire the next generation, inject innovation into the national economy, provide critical information needed to address national challenges, and support global engagement and international leadership. As the President has said, American footprints on distant worlds are not too big a dream. NASA is executing programs, step by step, to make this dream, and the broader quest to explore and understand the universe, a reality.

The missions that deliver these benefits are on track for some significant milestones in the coming years. The Parker Solar Probe, Transiting Exoplanet Survey Satellite (TESS), and the James Webb Space Telescope are on track to launch in 2018, and a new Mars rover is on pace for a 2020 launch. The first of a new series of experimental aircraft (X-planes) will fly in 2021 to begin investigating low boom supersonic flight. Working with commercial partners, NASA will fly astronauts on the first new crew transportation systems in a generation from American soil in 2018. We are continuing the development of solar electric propulsion for use on future human and robotic missions. NASA is fabricating and assembling the systems to launch humans into lunar orbit not later than 2023, as NASA works to open the space frontier. NASA's FY 2018 request supports progress toward these major milestones as part of the diverse portfolio of work the Agency executes as we explore, discover, and develop on behalf of the American people.

Science

NASA uses the vantage point of space to achieve – with the science community and our domestic and international partners – a deep scientific understanding of our home planet, the Sun and its effects on the solar system, other planets and solar system bodies, our galactic neighborhood, and the universe beyond. We focus our research on three overall, interdisciplinary objectives: 1) Safeguarding and improving life on Earth, 2) Searching for life elsewhere, and 3) Expanding our knowledge through research from here at home into the deep universe. NASA's FY 2018 budget requests $5,712 million for NASA's Science program, including $1,754 million for Earth Science, $1,930 million for Planetary Science, $817 million for Astrophysics, $534 million for the James Webb Space Telescope, and $678 million for Heliophysics.

This budget includes a new Science-Mission-Directorate-wide initiative to use small, less expensive satellites to advance selected high-priority science objectives in a cost-effective manner. This initiative will implement recommendations from the National Academy of Sciences, which concluded that, due to recent technological progress, these small satellites are suitable to address such science goals. All four science themes, to a varying degree, will focus technology development on CubeSats/SmallSats and targeted science missions to exploit this value. The initiative will also provide partnership opportunities between commercial partners, international counterparts, and NASA and further leverage and align with investments made within NASA.

NASA has a unique capability to develop and launch satellite missions to study Earth from space. In addition to designing and flying its own science missions, NASA develops weather satellites for NOAA and Landsat satellites for USGS. NASA Earth Science uses its 20 coordinated spaceborne missions, as well as suborbital and airborne platforms, to understand the Earth as an integrated system. Environmental data products derived from these observations are used in a range of real-world applications, including weather forecasts, agricultural production, water management, disease early warning, environmental trends, sea-level change and guiding responses to natural disasters. NASA's budget request of $1.8 billion enables a strong, stable program that continues these essential functions, and allows NASA to maintain its many public-private and international partnerships.

In the past year, NASA has successfully launched innovative satellites and spaceborne instruments, including the Cyclone Global Navigation Satellite System (CYGNSS) small-satellite constellation, two new instruments on the International Space Station (ISS), and several CubeSats. CYGNSS, a constellation of eight small satellites, was launched on December 15, 2016. Using reflected Global Positioning System (GPS) signals from the ocean surface, these satellites make first-ever, frequent measurements of winds and air-sea interactions in evolving hurricanes and tropical storms, providing insight into how these storms rapidly intensify. CYGNSS science data will be available for use and evaluation during the 2017 Atlantic hurricane season.

Looking forward, the FY 2018 request advances the Decadal Survey recommendation to ensure an ongoing vital fleet of research satellites to support science and applications. Recent highlights include the completion, launch, and initial operations of the Gravity Recovery and Climate Experiment Follow-on (GRACE-FO) mission. GRACE-FO will continue to track water across the planet and provide measurements used operationally in national drought monitoring products. Launch of GRACE-FO will occur in late 2017 or early 2018. Also in development, and on track for launch in the fourth quarter of calendar year 2018, is the Ice, Cloud, and land Elevation Satellite-2 (ICESat-2), which will measure ice sheet topography, sea ice thickness, cloud and aerosol heights, and vegetation canopy heights.

Landsat missions have provided the longest continuous, consistently processed set of global satellite measurements of the Earth – in 2018 this record will extend to 46 years. This budget request includes full funding for Landsat 9, a near-copy of Landsat 8, which is on track and targeted for launch in 2021.

Landsat 9, a collaboration between NASA and the USGS, is part of the overall Sustainable Land Imaging (SLI) architecture that will provide continuous, global land imaging through 2035. These and other new missions, combined with those now in orbit, will allow NASA to maintain a robust Earth Science program moving forward.

The request includes a reduction of $167 million from the FY 2017 Consolidated Appropriations level for Earth Science. These savings are accomplished by cancelling three missions in development as well as eliminating support for low-priority NASA instruments on NOAA's Deep Space Climate Observatory (DSCOVR) mission and reducing funding for Earth Science research grants. The reduction re-balances NASA's Science portfolio while minimizing impacts to operating Earth Science missions, and focuses on priorities of the science and applications communities.

With this year's budget request of $1.9 billion for Planetary Science, NASA continues to explore our solar system to help answer fundamental questions about our home and destiny in the universe, and to explore whether there is life beyond Earth. Planetary Science missions are exploring and operating throughout the solar system. Missions such as the Lunar Reconnaissance Orbiter at our Moon, as well as the rovers and orbiters at Mars, are informing us about our closest neighbors. Adding to our missions at Mars, the InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) lander will be launched in May 2018 to land on the surface in November. InSight is designed as a seismic and heat flow subsurface probe that will study the interior structure of Mars along with understanding its present-day level of global activity.

Further out in the solar system, NASA's Juno spacecraft achieved a first-ever polar orbit at Jupiter last July, and has already shown that Jupiter's magnetic fields are different and possibly more complicated than originally thought. NASA's New Horizons mission completed a successful flyby of Pluto and is more than halfway to its next target, the Kuiper Belt Object 2014 MU69. Meanwhile, the OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer) mission conducted a search for elusive objects known as Earth-Trojan asteroids while on its journey to the asteroid Bennu, arriving in August 2018.

After 13 years orbiting Saturn, our Cassini spacecraft has begun a series of 22 daring dives through the 1,500-mile-wide gap between the planet and its rings as part of the mission's "Grand Finale" end-of-mission maneuvers. When Cassini makes its final plunge into Saturn's atmosphere on September 15, it will send data from several instruments – most notably, data on the atmosphere's composition – until the very end of this highly successful mission.

With support from the FY 2018 budget request, NASA is continuing to develop our new Mars 2020 rover and Europa Clipper mission which will further the search for life beyond Earth. In January 2017, NASA selected two new Discovery missions, named Lucy and Psyche; these missions will expand our knowledge of asteroids and small bodies within the solar system.

NASA's Astrophysics program continues to operate the Hubble, Chandra, Spitzer, Fermi, Kepler, and Swift space telescopes, and the Stratospheric Observatory for Infrared Astronomy (SOFIA) airborne observatory, missions that together comprise an unrivaled resource for the study of our universe. NASA's next major Astrophysics mission, the James Webb Space Telescope (Webb), continues on schedule for its October 2018 launch and remains within budget. Webb will be a giant leap forward in our quest to understand the universe and our origins. The telescope will examine every phase of cosmic history: from the first luminous glows after the Big Bang to the formation of galaxies, stars, and planets, to the evolution of our own solar system. During FY 2017, the combined Webb telescope and instrument unit will be tested at the Johnson Space Center, and with the FY 2018 request, NASA will integrate this combination onto the spacecraft and prepare it for launch.

NASA will also complete the Transiting Exoplanet Survey Satellite (TESS) for launch in 2018. TESS will extend the pioneering exoplanet discoveries of the Kepler Space Telescope by looking for rocky exoplanets orbiting the nearest and brightest stars in the sky in time for Webb to conduct follow-up observations to search for markers of potential habitability. During FY 2018, NASA will continue formulation of the Wide-Field Infrared Survey Telescope (WFIRST). NASA's next Astrophysics Small Explorer, the Imaging X-Ray Polarimetry Explorer (IXPE), will continue development in FY 2018 for an expected launch in 2021.

NASA's Heliophysics program operates 18 active missions comprising 28 spacecraft, called the Heliophysics System Observatory (HSO), to understand the Sun and its interactions with Earth, the solar system and the interstellar medium, including space weather. NASA continues to gain important insight from the HSO, including new observations from the Magnetospheric Multiscale (MMS) Mission, which recently celebrated its second year in space this March. Later this year, NASA is looking forward to the launch of its Ionospheric Connection (ICON) mission, which will investigate the roles of solar forces and Earth's weather systems that drive extreme and unpredicted variability in the ionosphere. The FY 2018 request supports the continued development of the Parker Solar Probe and the Global-scale Observations of the Limb and Disk (GOLD) missions, both planned for launch in 2018. The Parker Solar Probe will fly closer to the Sun than any previous mission to study its outer atmosphere. GOLD, to be hosted on a commercial communications satellite, will measure densities and temperatures in Earth's thermosphere and ionosphere to improve our understanding and predictive capabilities for activity in this region, which is of crucial importance for space weather. The request will also enable the continued development of the critical instruments for the NASA-European Space Agency (ESA) Solar Orbiter Collaboration mission. Finally, NASA is continuing to implement the scientific community's priorities, identified in the latest Decadal Survey, including the recently announced Interstellar Mapping and Acceleration Probe (IMAP) opportunity as part of the Solar Terrestrial Probes Program.

By funding fundamental basic and targeted research opportunities, NASA will continue to develop and improve predictive models through enhanced understanding of the science of space weather. NASA, in coordination with other national and international agencies, will further the transition of research models to operations and seek to improve models already in operation through collaboration with operators, model developers, and researchers. Better understanding of space weather could help protect our technological infrastructure on Earth, including the Nation's electrical grid.

Aeronautics

NASA's Aeronautics Research program advances U.S. global leadership by developing and transferring key enabling technologies to make aviation safer, more efficient, and more environmentally friendly. With a request of $624 million for Aeronautics, the FY 2018 budget takes the next significant step in the New Aviation Horizons initiative – a bold series of X-planes – and systems demonstrations to support the goals of enabling revolutionary aircraft and improving the efficiency of the national air transportation system. With the FY 2018 request, NASA will demonstrate and validate transformative concepts and technologies as integrated systems in flight to meet the most challenging needs of aviation. Specifically, in FY 2018, NASA will award a contract for detailed aircraft design, build, and validation of the first X-plane, a Low Boom Flight Demonstrator (LBFD) that will demonstrate quiet overland supersonic flight and open a new market to U.S. industry. The LBFD X-plane is expected to achieve first flight by FY 2021, initially focused on flights to ensure safe operations and then proceeding to its sonic boom noise testing flight campaign. NASA has laid the groundwork for this initiative through years of research at the component level, through computer modeling, and with ground tests, and will now move on to critical flight tests. NASA is also laying the groundwork through tests and studies for a second X-plane, a subsonic flight demonstrator notionally scheduled for a first flight in FY 2026 that will show

revolutionary improvements to fuel efficiency and airport noise to reinforce U.S. technological leadership in the next generation of commercial aircraft.

NASA's request for Aeronautics will ensure investment in developing revolutionary tools and technologies ranging from hybrid and all-electric aircraft, autonomy, advanced composite materials and structures, data mining, verification and validation of complex systems, and revolutionary vertical lift vehicles, to enabling further advances for transformative vehicle and propulsion concepts that will address a broad array of our aviation industry's needs. NASA will continue to cultivate multi-disciplinary, revolutionary concepts to enable aviation transformation and harness convergence in aeronautics and non-aeronautics technologies to create new opportunities in aviation. In partnership with industry, NASA will explore technology advancements such as advanced lightweight aircraft structures to enable higher performing, more efficient subsonic aircraft configurations.

NASA will conduct flight demonstrations in a new configuration of the X-57 Maxwell, a general aviation-scale aircraft that will test highly integrated distributed electric propulsion technology. These tests represent a crucial step in the flight test process as conventional-fuel engines will be replaced with electric motors and electrical storage and power distribution systems, providing real-world data on all-electric flight. NASA will continue to advance the state of the art in hypersonic flight through technology demonstrations and computational and design tool development in partnership with other Federal agencies, leveraging flight test data to support NASA's research while simultaneously reducing risk and enhancing the effectiveness of other agencies' programs. NASA's efforts are aimed at reducing the uncertainty in computational models and ground testing, as well as flight testing operations. Overcoming these barriers will enable more effective technology risk tools, allowing for a better understanding of the true potential of future hypersonics technologies.

NASA continues to advance research and development into the air traffic management system to realize the Federal Aviation Administration's (FAA's) full vision for the Next Generation Air Transportation System (NextGen). NASA has recently begun a series of major flight tests to demonstrate significantly more efficient arrival and departure operations in full partnership with FAA and industry. Moving key concepts and technologies from the laboratory into the field through demonstrations ultimately will benefit the public by increasing capacity and reducing the total cost of air transportation. NASA will develop and demonstrate innovative solutions that enable use of new vehicle technologies through proactive mitigation of risks in accordance with target levels of safety, and provide analyses and safety assessments supporting use of analytical models in the specification, design, and analysis of complex, safety-critical aviation systems. NASA will also continue to lead the world for enabling safe Unmanned Aircraft Systems (UAS) operations by demonstrating key technologies that will integrate UAS operations in the National Air Space, as well as realize safe, low-altitude operations of small UAS through development of the UAS Traffic Management concept, or UTM.

Across all of these research areas, NASA investments will nurture U.S. university leadership in innovation that will foster and train the future workforce, and leverage non-aerospace technology advancements. Specifically, NASA will execute the first competitive University Leadership Initiative awards under the University Innovation Challenge project. These awards will sponsor research by university leaders who have independently analyzed the technical barriers inherent in achieving the Aeronautics Research Mission Directorate strategic outcomes, and who have proposed multi-disciplinary technical challenges along with supporting activities to address those barriers.

Space Technology

NASA's FY 2018 request includes $679 million for Space Technology to conduct rapid development and incorporation of transformative space technologies that will create opportunities for the U.S. aerospace

industry, enable NASA's future missions, and increase the capabilities of other U.S. agencies. NASA's Space Technology program has developed a diverse portfolio creating a technology pipeline to solve the most difficult challenges in space.

Technology drives exploration by continuing the maturation of enabling technologies for future human and robotic exploration missions, including deep space optical communications to return more data and improve operations, high power solar electric propulsion technologies for highly efficient in-space transit, high performance spaceflight computing, autonomous and hazard avoidance landing, extreme environment solar power, and advanced materials to improve rover mobility performance at low temperatures.

NASA will continue to prioritize "tipping point" technologies and early-stage innovation with more than 600 awards to industry and small businesses, private innovators, and academia to spark new ideas to support the broader U.S. aerospace and high tech sectors as well as for the benefit of NASA. As we complete these efforts, appropriate technologies will be transferred and commercialized to benefit a wide range of users, ensuring that our Nation realizes the full economic value and societal benefit of these innovations. Space Technology's partnerships engage more than 380 companies and continue to be a major priority in 2018.

The Green Propellant Infusion Mission spacecraft and the Deep Space Atomic Clock instrument will both be delivered to orbit as part of the U.S. Air Force Space Technology Program-2 mission aboard a SpaceX Falcon 9 Heavy booster slated for late 2017. The Green Propellant Infusion Mission will demonstrate a propulsion system using a propellant that is less toxic and has approximately 40 percent higher performance by volume than hydrazine, and which will reduce spacecraft processing costs. The Deep Space Atomic Clock demonstrates navigational accuracy improvements (with 50 times more accuracy than today's best navigation clocks) for deep space and improved gravity science measurements.

With the FY 2018 request, the Restore-L satellite servicing project will be restructured to reduce its cost and support a nascent commercial satellite servicing industry. This project will continue the development of key technologies, including rendezvous and proximity operations sensors, propellant transfer systems, and other robotic tools that will enhance and enable future NASA science and exploration missions. NASA is also pursuing a potential collaboration with the Defense Advanced Research Projects Agency and industry to most effectively advance satellite servicing technologies and ensure broad commercial application. NASA is continuing the Robotic Refueling Mission 3 that will focus specifically on servicing cryogenic fluid and xenon gas interfaces, which will support future scientific missions as humans extend their exploration farther into our solar system. Building on the Robotic Refueling Mission technology demonstrations on ISS, Space Technology will advance servicing technologies and partner with domestic private enterprise to commercialize the results, establishing a new U.S. industry.

NASA continues development of high-powered solar electric propulsion. This technology is scalable, widely applicable to human and robotic missions, and is a critical component of NASA's future exploration plans. In FY 2018, NASA plans to complete ground testing of the Solar Electric Propulsion engineering development units for magnetically-shielded Hall effect thrusters. We will begin fabrication of spaceflight-qualified hardware scheduled for delivery in 2019.

Upon completion of hardware build, the Laser Communications Relay Demonstration project will start integration and test to support a FY 2019 Launch Readiness Date. The Mars Oxygen In-Situ Resource Utilization Experiment and Terrain Relative Navigation projects will complete hardware development, and will enter into integration and test to support the Mars 2020 schedule. In addition, the Mars Environmental Dynamics Analyzer and Mars Entry, Descent, and Landing Instrument 2 will successfully

complete technology development, and be delivered for Mars system integration and test on the Mars 2020 robotic lander mission.

NASA will also complete testing of a 1kW fission reactor that could aid in a potential future design of a 10kW-class system. Fission reactor systems have the potential to provide abundant energy for surface exploration. Full ground testing at design temperatures is planned for early FY 2018 at the Nevada Nuclear Security Site.

Human Exploration and Operations

The FY 2018 request includes $3,934 million for Exploration, with $3,584 million for Exploration Systems Development, and $350 million for Exploration Research and Development. The FY 2018 request also includes $4,741 million for Space Operations, including $1,491 million for the International Space Station (ISS), $835 million for Space and Flight Support, and $2,415 million for Space Transportation – both commercial crew system development and ongoing crew and cargo transportation services that resupply the ISS. The request provides the necessary resources in FY 2018 to support development as planned of the SLS rocket and Orion crew capsule, as well as on the technologies and research needed to support a robust exploration program. The budget creates new opportunities for collaboration with industry on ISS and supports public-private partnerships for exploration systems that will extend human presence into the solar system.

The ISS is the first step on the road to deep space exploration, a nearby outpost in space where humanity has taken its early steps on its journey into the solar system. This unique microgravity laboratory is delivering the knowledge and technology we need to keep our astronauts safe, healthy, and productive on deep space missions of increasing durations. This knowledge and technology are the cornerstones of our exploration strategy. Research on the ISS has advanced the fundamental biological and physical sciences for the benefit of humanity, improving life on Earth, and adding to our understanding of the universe. The ISS forms the foundation of the Nation's global leadership in space exploration through the ISS International Partnership of five space agencies representing 15 nations.

Under the original Commercial Resupply Services (CRS) contracts, our two commercial cargo partners, Space Exploration Technologies (SpaceX) and Orbital ATK, are providing cargo deliveries to the ISS. Using the space launch vehicles developed in partnership with NASA, SpaceX and Orbital ATK have also helped to bring some of the commercial satellite launch market back to the U.S. and have reduced commercial launch costs. Under new CRS-2 contracts, SpaceX, Orbital ATK, and Sierra Nevada Corporation will deliver critical science, research, and technology demonstrations to the ISS over five years from 2019 through 2024. Working with our commercial crew partners, SpaceX and the Boeing Company, NASA plans to return crew launch capability to American soil in 2018. The FY 2018 request provides critical resources in this exciting and challenging period as we work with our partners to launch the first new U.S. human spaceflight capability in a generation.

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. Through CASIS' efforts, the ISS National Lab has reached full capacity for allocated crew time and upmass and downmass, and is expected to continue at this level of activity for the foreseeable future.

NASA's activities in low Earth orbit (LEO), including research aboard ISS and the use of commercial crew and cargo transportation services, are encouraging the broader commercial development of LEO. The ISS serves as the focal point for NASA's LEO commercialization development efforts by enabling

private industry to foster new markets – such as space tourism or satellite servicing – by developing and maturing their own capabilities and services for Government and non-Government customers. These new markets could also support platforms on which NASA would be only one of many Government and non-Government customers.

As we move out beyond LEO, we will employ new deep space systems, including the heavy-lift Space Launch System (SLS), Orion crew vehicle, the Exploration Ground Systems (EGS) that support them, and new deep space habitation capabilities to be developed through public-private partnerships and international partnerships.

NASA plans to launch an initial, uncrewed deep-space mission, Exploration Mission-1 (EM-1), in 2019. The mission will combine the new heavy-lift SLS with an uncrewed version of the Orion spacecraft on a mission to lunar orbit. A crewed mission, EM-2, will follow not later than 2023; the FY 2018 budget fully funds the Agency baseline commitment schedule for EM-2 and the Orion spacecraft. Missions launched on the SLS in the 2020s will establish the capability to operate safely and productively in deep space.

SLS, Orion, and EGS are the critical capabilities for maintaining and extending U.S. human spaceflight leadership beyond LEO to the Moon, Mars, and beyond. For SLS, the nationwide NASA and industry team has completed five years of detailed engineering design and is now in large-scale hardware production and testing for EM-1 and subsequent flights. Core Stage hardware is taking shape inside the 43 acres of factory floor space at the Michoud Assembly Facility (MAF) in Louisiana (where work continues despite a tornado which hit the facility this February), while SLS Boosters, Core Stage Engines, and other flight hardware are also in production and testing in Alabama, Utah, Mississippi, and facilities elsewhere across the country. For Orion, the EM-1 flight Crew Module is being welded and outfitted at the Kennedy Space Center (KSC), software development and testing continues in Colorado and Texas, and the European-provided Service Module structural article has successfully completed testing at Plum Brook Station in Ohio. At KSC, NASA has completed installation of all ten work platforms in the giant Vehicle Assembly Building (each weighing up to 380,000 pounds, aligned with pinpoint precision), outfitting continues on the 355-foot-tall Mobile Launcher, and historic Launch Pad 39B is being prepared with new flame trench bricks and support systems. These are the early steps on a journey that leads American astronauts into deep space, permanently.

The FY 2018 request also includes funding for exploration research and development that will make future missions safer, more reliable, and more affordable. Among these efforts, NASA is now working 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 partners 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. The NextSTEP efforts are a key component, along with international partnerships and NASA technology development, of our overall strategy to move into deep space, and NASA intends to perform integrated ground testing using habitation capabilities developed by the NextSTEP partners in 2018.

We will continue to investigate approaches for reducing the costs of exploration missions to enable a more expansive exploration program.

With the FY 2018 request, the Asteroid Redirect Mission (ARM) is no longer included in NASA's exploration plans, but key work done for the mission will be carried forward to support NASA's human exploration efforts, particularly in the area of solar electric propulsion. 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. More details on NASA's plans will be detailed in the exploration roadmap requested by the Congress in the NASA Transition Authorization Act of 2017.

The budget request provides for critical infrastructure indispensable to the Nation's access and use of space, including Space Communications and Navigation (SCaN), Launch Services Program (LSP), Rocket Propulsion Testing (RPT), and Human Space Flight Operations (HSFO).

Management and Efficiency

NASA's FY 2018 budget proposes the termination of the Office of Education (OE) and its portfolio of programs and projects. The Office of Education has experienced significant challenges in implementing a focused NASA-wide education strategy, including providing oversight and integration of Agency-wide education activities. The FY 2018 budget supports the orderly closeout and/or transition of these activities needed to comply with Federal laws and regulations regarding contracts, grants/cooperative agreements, civil servants, records management, and administrative infrastructure. While this budget no longer supports the formal OE programs, NASA will continue to inspire the next generation through its missions and the many ways that our work excites and encourages discovery by learners and educators. The Science Mission Directorate (SMD) Science, Technology, Engineering, and Mathematics (STEM) Science Activation program will continue to focus on delivering SMD content to learners of all ages through cooperative agreement awards. NASA does not intend to transfer ownership of programs formerly funded by OE to SMD, as these activities fall outside the scope and resources of the SMD STEM Science Activation program.

As is noted in the Government Accountability Office's (GAO) February, 2017 "High Risk Series" report, NASA efforts at improving program management and performance for major developments is yielding tangible results in the form of improved estimates, and better cost and schedule performance. As GAO notes: "in 2016, overall development cost growth for the portfolio of 12 development projects fell to 1.3 percent and launch delays averaged 4 months. Both of these measures are at or near the lowest levels we have reported since we began our annual assessments in 2009" (these measures exclude Webb, which was rebaselined in 2011).

NASA's Mission Support Directorate directly enables NASA's portfolio of missions in aeronautics, space technology, science, and space exploration. The FY 2018 request provides the operations, tools, equipment, and capabilities to safely operate and maintain NASA Centers and facilities and the independent technical authority required to achieve program objectives for all NASA missions. With installations in 14 states, NASA collectively manages $39 billion in constructed assets with an inventory of over 5,000 buildings and structures. Our focus is on renewing and sustaining only what is crucial to mission success and divesting of unneeded older, costly real property to lower the cost of operations.

NASA is transforming the management of information technology (IT) and improving cybersecurity by implementing the results of an internal IT Business Services Assessment (BSA) and working to improve compliance with the Federal Information Technology Acquisition Reform Act (FITARA) and the Federal Information Security Modernization Act (FISMA). Two of our key goals are to create a complete inventory of NASA's IT assets and better secure NASA's networks. The budget request includes an increase of $32 million in cybersecurity and IT management spending, which will be used to complete stronger Personal Identity Verification (PIV) compliance, mature Security Operation Center (SOC) capabilities, improve detection and response to malicious activities, and develop and deploy IT Portfolio Management tools and processes. The increase will support NASA's efforts to provide the appropriate

visibility and involvement of the Office of the Chief Information Officer in the management and oversight of IT resources across the Agency.

To maintain critical capabilities and successfully meet current and future mission needs, NASA will continue its implementation of an Agency Operating Model that involves a disciplined, multi-year effort that engages the participation of all nine NASA Centers, the Jet Propulsion Laboratory, and four Mission Directorates, as well as NASA senior management. The NASA Operating Model seeks to advance best-in-class capabilities by alignment to recognized Centers; to ensure that technical capabilities are matched to mission need; to enable mutual dependencies among NASA Centers, programs, and the leadership team to meet mission challenges; to build flexibility in NASA's institutional resources to support a modern, agile workplace; and to ensure that decision making considers the outcomes for the successful performance of the Agency as a whole.

Conclusion

The program of exploration and discovery we propose to execute with the FY 2018 request should be a source of pride to the Committee, the Congress, and the American people. With constancy of purpose and consistent support from the Congress, we look forward to extending human presence into deep space, exploring potentially habitable environments around the solar system, deepening our understanding of our home planet, pushing our observations of the universe back to the time when the first stars were forming, and opening the space frontier. While the future benefits of discovery are always difficult to predict, our past and present give us confidence that the resources we are requesting represent an investment that will return to the Nation multiplied many times.

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

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Robert M. Lightfoot, Jr.
Administrator (Acting), NASA Headquarters

Robert M. Lightfoot Jr. became NASA's Acting Administrator effective January 20, 2017. His permanent title is Associate Administrator for NASA, the Agency's highest-ranking civil servant position, effective since September 25, 2012.

He previously was director of NASA's Marshall Space Flight Center in Huntsville, Ala. Named to the position in August 2009, he headed one of NASA's largest field installations, which plays a critical role in NASA's space operations, exploration and science missions. Lightfoot managed a broad range of propulsion, scientific and space transportation activities contributing to the nation's space program. He served as acting director of the center from March 2009 until his appointment as director.

From 2007 to 2009, Lightfoot was deputy director of the Marshall Center. Lightfoot served as manager of the Space Shuttle Propulsion Office at Marshall from 2005 to 2007, where he was responsible for overseeing the manufacture, assembly and operation of the primary shuttle propulsion elements: the main engines, external tank, solid rocket boosters and reusable solid rocket motors.

From 2003 to 2005, he served as assistant associate administrator for the Space Shuttle Program in the Office of Space Operations at NASA Headquarters in Washington. His responsibilities included space shuttle return to flight activities following the Columbia tragedy, technical and budgetary oversight of the $3 billion annual budget and initial transition and retirement efforts for shuttle infrastructure.

In 2002, Lightfoot was named director of the Propulsion Test Directorate at NASA's Stennis Space Center. He served as deputy director of the organization beginning in 2001, until his appointment as director.

Lightfoot began his NASA career at the Marshall Center in 1989 as a test engineer and program manager for the space shuttle main engine technology test bed program and the Russian RD-180 engine testing program for the Atlas launch vehicle program.

Lightfoot received a bachelor's degree in mechanical engineering in 1986 from the University of Alabama. In October 2007, he was named Distinguished Departmental Fellow for the University of Alabama, Department of Mechanical Engineering. He was selected as a University of Alabama College of Engineering fellow in 2009. Lightfoot serves on the University of Alabama Mechanical Engineering Advisory Board. In 2010, he was inducted into the State of Alabama Engineering Hall of Fame.

Lightfoot has received numerous awards during his NASA career, including a NASA Outstanding Leadership medal in 2007 for exemplary leadership of the Shuttle Propulsion Office, assuring safety for the return to flight of the space shuttle. In 2006, he was awarded the Presidential Rank Award for Meritorious Executives, and in 2010 and 2016, he received the Presidential Rank Award for Distinguished Executives -- the highest honors attainable for federal government work. In 2000, Mr. Lightfoot received a Spaceflight Leadership Recognition Award, which recognizes leaders who exemplify characteristics necessary for success. In 1999, NASA's astronaut corps presented him with a Silver Snoopy Award, which honors individuals who have made key contributions to the success of human spaceflight missions. He also received the NASA Exceptional Achievement Medal in 1996 for significant contributions to NASA's mission.

Chairman BABIN. Thank you, Mr. Lightfoot. I appreciate it. Thank you.

The Chair recognizes himself for five minutes for questioning. And again, thank you for being here. We really appreciate you.

The GAO recently found that both of the commercial crew contractors are likely to be delayed into 2018 into 2019. Under normal contracting mechanisms, there would be a penalty associated with not meeting schedules. My understanding is that under these contracts the penalty is simply not receiving payment until the work is completed.

GAO also recently found that the SLS and Orion programs would also face schedule delays. Conversely, under those contracts, my understanding is that the contractors could face the loss of award fees. Can you explain which model provides the government the best tools to procure a system or service in the most timely and least costly manner?

Mr. LIGHTFOOT. Yes, sir, great question. We have—you know, both groups continue to make great progress, and when we did the commercial crew program, we tried a new acquisition strategy approach with fixed-price contracts where, when they slip, we do simply just pay when they make their milestones. We have had success with both processes. If you look at TDRS, which we fly today, it was a fixed-price contract as well.

And what we do internally in the agency is we make an assessment from an acquisition perspective which way is the best way for us depending on the amount of development. If there's a lot of development, we figured—we feel like cost-plus is the way to go because we may not have the perfect requirements nailed down. We felt pretty confident in our requirements when we went to the commercial crew guys and we felt we could go fixed-price.

So that's really how we assessed it. We have what's called an acquisitions strategy process that allows us to make an assessment which way we're going to go as we move forward. So that's how we did this one, and we think both are options that we should always consider when we do this.

Chairman BABIN. Yes, okay. Thank you. And then regarding science, the decadal process plays a significant role in how NASA prioritizes and how Congress funds scientific missions. This budget proposes cancellation of several earth science missions that were never recommended by the decadal process, specifically, PACE, OCO–3, RBI, and DSCOVR, EPIC, NISTAR, and NISTAR instruments.

With the next earth science decadal survey forthcoming, the request also rightly proposes cancellation of the CLARREO Pathfinder. CLARREO could potentially cost in excess of $5 billion, and it is in the early stages of development. Decisions about the mission would be well served by more information from the community. All of this begs the question, why are we funding missions that were not prioritized by the decadal process?

Mr. LIGHTFOOT. Well, Mr. Chairman, we have always looked at the decadal process as our guiding principle from that perspective, but there's other things we can do outside of the decadals. When we got the budget for this year for the 2018 budget, we went back to our principles of decadals and we said—we used kind of a three-

tier process. We said what's in the decadals, what's in the—what are the—is this the best science value for return for what we're doing, and then how are they performing? So some of the issues like RBI we were having some performance issues associated with that. And so that's how we came up with a list of ones that we proposed coming back to you guys for the fiscal year 2018 budget.

Chairman BABIN. Okay. And Mars is often referred to as a horizon goal for human space exploration. However, if we are careless in our planning, Mars exploration could become unsustainable, perhaps even a dead-end. So how would the Deep Space Gateway make exploration to Mars more sustainable and help NASA to achieve its mission of extending human presence throughout the solar system?

Mr. LIGHTFOOT. We believe that what we need is an infrastructure throughout—from low-Earth orbit to get to Mars we're going to need some infrastructure along the way. And the Gateway concept, which is just a concept at this point, actually provides us kind of a steppingstone approach, and we figure that's the better way to do it if you go from a stepping—if you take it one step at a time, we think we can actually get there in a more efficient way.

It also gives an opportunity for public-private partnerships to come into play, and we think there's a good mix that we can do. And if you do it in the steppingstone way, you're not committing to the final answer first. You're doing it in a pretty measured way that I think is consistent with the budgets that we have.

Chairman BABIN. And one last question. The Administration has expressed interest in public-private partnerships. When used appropriately, funded Space Act agreements are very useful—a useful tool to advance partnerships. NASA's current policy limits the use of funded Space Act agreements to cases where contracts, grants, and cooperative research and development agreements cannot achieve agency objectives. This ensures that there is proper oversight of the use of funded Space Act agreements. Does NASA intend to keep this policy in place?

Mr. LIGHTFOOT. Yes, sir. We think we got—we use the entire suite of tools we have for acquisition, and I think we can—we'll keep that policy in place.

Chairman BABIN. Okay. Thank you very much.

And now, I'd like to recognize the Ranking Member of our Subcommittee, Mr. Bera.

Mr. BERA. Thank you, Mr. Chairman.

Just continuing on Chairman Babin's line of questioning, with Mars as a longer goal and thinking about that and looking at the budget for Space Launch—for SLS and the Orion crew vehicle—and it does look like it comes in for Orion about $164 million under fiscal year 2017 budget, as well as $212 million for SLS relative to the fiscal year 2017. How does this impact our ability to get to Mars if our goal is still, as many of us on this Committee have said, by 2033? So——

Mr. LIGHTFOOT. Yes, I think the budget we've proposed has got the systems we need in 2018 to keep making the progress we think we need to make on all the different systems we have. Clearly, we think we're going to need something commensurate with inflationary growth or economic growth going forward as we move for-

ward, but for '18 for this budget, we think we'll make the progress we need to make on all the systems to get us to our goals of the Moon and Mars down the road. So——

Mr. BERA. And also, you know, there's a proposed termination of the Asteroid Redirect Mission. Part of the thought there was also when that mission was in place was the next generation of propulsion systems, particularly solar electric propulsion. I'd be curious, with the proposed termination of that mission, how's that going to impact solar electric propulsion?

Mr. LIGHTFOOT. Yes, this budget keeps solar electric propulsion in there. One of the things that we discovered in the work on the Asteroid Redirect Mission is that's a pretty big enabler for us on some of the things we can do, especially in the infrastructure we're going to need around the Moon.

Mr. BERA. Right.

Mr. LIGHTFOOT. So we're proposing to keep that and we'll continue developing that in space technology and use it as part of something like a power propulsion bus that we'll use around the Moon as the core for some of the infrastructure we need.

Mr. BERA. So you'll continue to work in that direction——

Mr. LIGHTFOOT. Yes, sir.

Mr. BERA. —if you've got the resources? And last thing in my opening comments I talked about the importance of inspiring the next generation of astronauts, our kids and grandkids. How does NASA, you know, again with the current budget that's being proposed for the coming fiscal year propose to continue its education mission?

Mr. LIGHTFOOT. Yes, so we've been working on that for a while with—internal to NASA in terms of the better way to actually deploy our educational activities that we do in a more efficient way. So that was one thing we were working before this came out.

The other thing that we truly believe is that our entire budget is for inspiring the next generation. I mean, if you think about yesterday's event with the astronaut candidates, I mean, it was just really awesome to see the excitement around that and excitement it generated. The emails I've got today from just people I know, public I know that they said this is really neat. And that wasn't an education event; that was us talking about our missions. And I think our missions are what inspire people, and I think as long as we're doing the missions we're doing, we'll continue to inspire the next generation.

Mr. BERA. And do you feel within the current budget you'll have the ability to go out to schools and continue to do some of that direct education stuff?

Mr. LIGHTFOOT. Yes, what we've done is we've got a baseline services activity we're doing inside the agency to sync—better sync up our education activities with our outreach activities so make sure that they're better aligned we go out, and we absolutely think we'll continue those activities.

Mr. BERA. Okay. And then also, obviously, these are multiyear missions, multiyear strategic planning as we're looking at longer-term goals. You know, the Chairman brought up the International Space Station and we've committed to funding through 2024. Obviously, that's one thing we've certainly been meeting with folks,

chatting with folks at NASA, as well as others, the potential possibility as more commercial entities get into space, as other institutions see this valuable asset and the academic sector and others, the potential of life after 2024. And I'd be curious in NASA's long-term planning how are you guys thinking about the ISS in longer-term?

Mr. LIGHTFOOT. Well, as you said, we're approved till 2024——

Mr. BERA. Right.

Mr. LIGHTFOOT. —and what we're working on now is what are the transition indicators as we would call them? There's very technical reasons you can go into, science, technologies we can do, but there's also the question of that is a destination——

Mr. BERA. Right.

Mr. LIGHTFOOT. —for a lot of folks, you know, other than just us, and it's an enabler frankly of the commercial industry. So we're looking at that now. We're not planning on going past 2024, but we're actually talking about what would it do. And I think as a policy for the United States, we have to decide whether, you know, it's a symbol of our leadership up there, too, right?

Mr. BERA. Well, now's the time to do that planning, right? So we don't——

Mr. LIGHTFOOT. Yes, that's what we do.

Mr. BERA. —start that conversation in 2023.

Mr. LIGHTFOOT. Yes, agreed.

Mr. BERA. Right. Thanks. I'll yield back.

Chairman BABIN. Thank you, Mr. Bera.

I now recognize the Chairman of the full Committee, Mr. Smith from Texas.

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

Mr. Lightfoot, I've already commented on the budget, so let me ask you some general questions, but let me preface them by pointing out the obvious, and that is the American people are absolutely fascinated by space. They're fascinated by space exploration, they are fascinated by the night sky. I think there is a real good reason why the Air and Space Museum here in DC. is the most popular museum in America. It's not an art museum in California, it's not a history museum even in D.C., it's the Air and Space Museum.

And we had an indication of interest in our space program yesterday when we were at Johnson Space Center, and we had twice as many people as ever before apply to be an astronaut. And it is absolutely incredible to me we had 18,000 applications for 12 spots. And that comes out to I think one to every 1,500 applications, probably the hardest job to get in America without any question, but on the other hand, they are our real heroes today and will be tomorrow.

When we think about space exploration and how inspired the American people are by it, another example would be the discovery of what, in just the last 12 years of 3,500 exoplanets, several dozen Earthlike planets, and every time there's any kind of discovery in space, it makes the front page of the papers, it leads the news at night, and so forth.

But my general question is this: What do you think are the most exciting things happening in space today? What is going to seize

the imagination of the sixth-grader walking to school or the adult in their homes?

Mr. LIGHTFOOT. I think you kind of nailed it with your preface there. To me I think there's—anything that we do with humans is one piece of that. When you can actually see another human doing something in space, it really is——

Chairman SMITH. Yes.

Mr. LIGHTFOOT. —in our DNA to explore and I think people feel part of that. But on the science side and the aeronautic side if you look at the discoveries we're making from the science standpoint, when we found TRAPPIST–1, the seven exoplanets—you know, potential exoplanets around the star, four billion hits on our social media, four billion in all our different platforms that we have. That's incredible. I mean, that's the kind of region interest that people have in what we're doing. And I think—again, I think it's just the fact that people are—they're inspired by anything we discover, right, because you're challenging things that we thought we knew. And I think that's what—so as long as we're doing the good missions and the big missions like we're talking about, I think the inspiration will be there.

Chairman SMITH. Okay, good. Let me ask you a more specific question and a leading question, and it's a subject that I'm fascinated by. And that is that sometime what may be in the next five to ten years we're going to have the capability of analyzing the spectra of Earthlike planets and being able to determine, for example, whether there is methane or oxygen in the atmosphere, and if so, that is very strong evidence that there is something alive on the surface. It may be vegetative, it may be sentient. we don't know. But what do you think we might discover over the next few years that will possibly be the biggest space news in a century?

Mr. LIGHTFOOT. Wow. From my crystal ball perspective, I think—really, I don't know what that discovery will be. You know, I don't think ten years ago I could've told you we'd have had 3,500 exoplanets——

Chairman SMITH. Yes.

Mr. LIGHTFOOT. —right? But I think what we're doing is we're working on the systems that allow us to make those civilization-level discoveries, the kind that really impact us as humanity. If you look at WFIRST, the Widefield telescope we're going to put up, we're working that to have a starshade that goes front of it so that we can actually see even more——

Chairman SMITH. Yes.

Mr. LIGHTFOOT. —of these potential planets throughout the universe. That's exciting. And then we can make some plans, right? You know, not in my lifetime but we can make some plans on how do we reach out to those locations. And so I think if we could—to me, you know, our goal at the agency and the science community has always been is their life out there, and if so, what is it and where is that, right?

Chairman SMITH. Exactly.

Mr. LIGHTFOOT. If we find that, that's a civilization-level impact I think.

Chairman SMITH. Yes, I agree completely. You also make a good point, and that is it's hard to predict. And sometimes our imagina-

tions can't even conceive of what might happen in the future. A good example of that would be of course that it was only 50 years before the Wright brothers flying the sort of contraption 60 seconds about 30 feet above the ground, 50 years between that and putting six astronauts walking on the surface of the Moon, so we really don't know what the future holds. We only know what will be fascinating and inspiring.

Mr. LIGHTFOOT. And the research we're doing on the International Space Station, you never—that could——

Chairman SMITH. Same thing.

Mr. LIGHTFOOT. If we find something, we just—you know, that's what we're working there for.

Chairman SMITH. Right. Thank you, Mr. Lightfoot.

Thank you, Mr. Chairman.

Mr. LIGHTFOOT. Thank you, sir.

Chairman BABIN. Fascinating questions, thank you.

Now, I recognize the gentleman from Oklahoma, Mr. Lucas.

Mr. LUCAS. Pass, Mr. Chairman.

Chairman BABIN. Okay. All right. Let's see, you know what, I went to the wrong direction. I'm sorry. I apologize. The gentleman from Virginia, Mr. Beyer.

Mr. BEYER. There are so many people down there; I understand it completely. And I'm going to just begin by thanking Chairman Smith and Chairman Babin for holding this and also just for the shared bipartisan enthusiasm that we have for space.

And, Mr. Lightfoot, I just think about following up on Chairman Smith's—with what you're doing with James Webb, with Mars, with the ISS, with the Pluto stuff which was so exciting, and we got a chance to visit with the heliophysics people out at Goddard, which is terrific, the hearings we've had on SETI, and especially thank you for the investments in Wallops. In Virginia we very much want to be part of space.

And by the way, I'd like to suggest to Chairman Smith, if you can find hyperspace and find ways to overcome the distance problems that we have in space, that would be terrific for NASA to do. It's not yet in your mission but—questions: Your budget proposes total elimination of the $100 million for the Office of Education. And I understand reading the stuff that there are issues with strategy and outcome-related data and you need to rethink it. I'm concerned about the complete elimination of that Office of Education when everything we hear is that we need a lot more scientists, mathematicians, and engineers, that STEM education has to be the heart of education moving forward. So how do we reconcile this tremendous need for more mathematicians, scientists with eliminating this office?

Mr. LIGHTFOOT. Yes, sir. I think one of the things that we worked on was trying to—as I said earlier, try to—trying to integrate our education outreach a little better from the overall formal program. I think the important thing to remember is we still do a ton of education within our mission directorates. In aeronautics, for instance, we have the university innovation and challenges activity where we actually fund undergraduate research and graduate research to do some of our technical challenges. We have the STEM science activation activity in science is still there. We have the

NASA space technology graduate research—research fellowships that are still there. There are several programs still running in the missions that actually—we actually engender folks to actually come help us solve some of the technical challenges we have. So that's another way that we actually invest in the STEM workforce for the future for us. So—and that's still in this budget as we go forward.

Mr. BEYER. Our Chairman said—I'm paraphrasing—that NASA couldn't be the piggybank for climate change research that could be realistically done by other agencies. And I looked just at the five that are going to be eliminated, the Plankton Aerosol Clouds and ocean Ecosystem, Orbiting Carbon Observatory, the Climate Absolute Radiance and Refractivity Observatory, the Radiation Budget Instrument, and Deep Space Climate Observatory. All those are out in space. Is there really any other institution of the Federal Government that could do those?

Mr. LIGHTFOOT. Well, I think for us, right, the spacecraft that we build and the ones that we put up are all part of what we think we do for earth science, which is inform the decision-makers on the risk to the planet, right? There are other agencies that we work complementarily with. We build the spacecraft for NOAA, for instance, and then we hand them over once they get them in orbit and get them operational. We work Landsat with USGS. These are missions that we do together. The 20 remaining missions we have in the agency for earth science we think provide the data that NASA should be providing to the decision-makers going forward. So I think we have a very robust earth science program right now going forward and will still provide the data that we can provide.

Mr. BEYER. Is the theory that these five out of the 25 are the least-high priority?

Mr. LIGHTFOOT. Yes, what we did is we did an assessment based on—if you look at the Earth, we kind of—I'm an engineer, not a scientist, right, so we took a risk management approach the way we looked at these missions and what we're going to go do, and if you look at the Earth as a system—and it is; it's an ecosystem that has a ton of different things that engage in what we do and how the Earth lives and operates—we took a look at that, we took—and we looked at the science value, where can we get the data that these missions were going to get, maybe not at the resolution or the degree we wanted, what's in the decadals, and then how are they performing from a performance—from a cost, schedule, and budget performance perspective? And that's how we came up with the list that we came up with.

Mr. BEYER. Great. Thank you. In the five-year budget it's fascinating how completely flat it is. It's $19,092,000 all the way out. But you figure with inflation—I think our data said 2.3 percent—it comes to a cumulative loss of $4.5 billion in purchasing power. So, you know, if you look at it just a little askance, it looks like the NASA budget is actually shrinking every year over this five-year period of time. So how do we—how can we argue that this is a long-term budget that truly reflects our robust commitment to space?

Mr. LIGHTFOOT. Yes, the—we have concerns about the out years as well. The '18 budget is good for us, and we'll be working on—in the '19 proposal process to work the—out—the flat-year thing

because it is—that's exact calculations we've had is $4.5 billion in loss of buying power over the next five years. So we'll work that in the next budget cycle going forward.

Mr. BEYER. Well, I'm hopeful that this will be something bipartisan we'll be fighting for your increased budget, too, over these next five years. Yes, thank you.

Mr. Chair, I yield back.

Chairman BABIN. Sir, thank you, Mr. Beyer.

And I now recognize the gentleman from Oklahoma, Mr. Bridenstine.

Mr. BRIDENSTINE. Thank you, Mr. Chairman.

Thank you, Mr. Lightfoot, for being here. And I think from both sides of the aisle up here, we're very grateful for your leadership at NASA for so many years and of course going through this transition and the continuity that Chairman Smith talked about is important. You've provided that, and we're all very grateful for your leadership there.

I wanted to bring up to start some of the processes related to earth science. You mentioned in the budget that you went through a process, you started with the decadal survey and then the science value and finally performance. And from that you were able to determine that these were the missions that were the most important and more in keeping with the budgetary constraints that NASA has to adhere to.

I think on both sides of the aisle we all want to make sure we know what's happening to the planet. We can disagree about the policies that need to be implemented from Congress, but we all want to know what is happening to planet Earth. Can you assure us, given this budget, that we're going to have the science and the data necessary to know what's happening to the planet?

Mr. LIGHTFOOT. Yes, we believe so. And I think the other thing that I haven't mentioned yet that I'll share is we have the next earth science decadal comes out in 2017, right? And we're——

Mr. BRIDENSTINE. Okay.

Mr. LIGHTFOOT. And for the one we're living to, it's 2007. Clearly, there's a lot of information since then, and so for us, it was a good opportunity to say, okay, let's see what the decadal says for—when it comes out, and we'll use that data actually to inform us in our next cycle if we need to make any changes on there. But I believe so in terms of how we've assessed where we can get all the data we need within the—again, looking at the Earth as a system——

Mr. BRIDENSTINE. Right.

Mr. LIGHTFOOT. —and all the pieces of the system, where can we get the pieces of data that help us assess that, the Earth as a system?

Mr. BRIDENSTINE. Okay. Fantastic. My second question, there was a lot of excitement in Congress, a lot of excitement throughout the entire nation, I think a lot of excitement at NASA when you made the determination that we were going to study whether or not we are going to put humans on EM–1. And earlier, you mentioned how important it was that when the American public and in fact the world, when they see humans in space doing stunning achievements, that that inspires the next generation, and I think there's broad agreement here as well. Can you go through the proc-

ess that you went through to determine whether or not to put humans on EM–1?

Mr. LIGHTFOOT. Yes, sir. We—you know, we talked to the Administration when they came in, and this is one of the things they asked us to look at. We looked at it before obviously, but we hadn't looked at it in a while. And what we did is we put a team in place to do—ask them to look at the feasibility, you know, could we technically do this. And the teams were—they were very—just like you said, very energized what they did.

The approach we took was go back two or three years to when we made this—when we made the decision to not fly crew and look and see what things we've done that we would have to back up and back out of to redo because now we're going to put crew. That's one example of the technical pieces. We asked the schedule, how much extra schedule would you need and then how much extra budget would you need going—to do all this?

It was a fascinating exercise just because it energized our teams, it provided us some insight in some areas we did not know people had concerns about necessarily, and so we're going to pull some testing forward. But at the end of the day when we had the discussion around this, we were going to increase the cost, we were going to slip the schedule a little bit, and we were going to accept some more technical risk than we had. And so it really just confirmed that the plan that we were on—that we had in place was actually a good one for us and the right one for us to go do. In the meantime, we'll go do some work on the heat shield for Orion. We'll probably advance an ascent abort test, move it forward, and some other testing that we found in the process.

But it really got the teams focused on what we need to do to get there. And so I—it was a good exercise, and I think, you know, we had to deal with the—there was some disappointment that we're not going to go try to do this, but I think people recognized at the end of the day that it actually focused us even better to try to get there.

Mr. BRIDENSTINE. Thank you, Mr. Chairman. I'll yield back.

Chairman BABIN. Yes, sir. Thank you.

And now, I'd like to recognize the gentleman from Illinois, Mr. Foster.

Mr. FOSTER. Yes, thank you, Mr. Lightfoot. And first, I'd like to congratulate you in general terms on your management of the whole unmanned science program and, you know, this is—you've been doing this in very trying times and have had to make a lot of our decisions, but I think, you know, as a—I guess the only Ph.D. scientist in Congress, I'm really excited to just think about what the James Webb Space Telescope is going to mean. It's—you know, people believe it's going to be a Hubble-like step in our understanding of the universe, and so I know that I am—probably almost all scientists on Earth are excited to see what that will reveal.

I'm less sanguine about the goals of the manned space program, you know, in particular the whole concept of having Mars as a horizon project as you say because, you know, when I look back at the fraction of GDP that was associated with actually paying for the Apollo program and, you know, the fact that it was paid for basi-

cally by having, you know, more than 80 percent marginal tax rates at the time on the wealthy, you know, then you have to imagine—you have to—for Congress to start planning that and to start preparing the public for it, we have to have some sort of zero-order cost estimate for that.

And so, you know, you can imagine going to Mars with different strategies. The traditional low-cost one is a massive heavy launch vehicle, which has traditionally been the low-cost way of doing things. You can imagine the infrastructure approach that you're talking about, step-by-step, and then you have to deal with the challenges of the operating cost for these things for which we I think have pretty good data now from the ISS of just the order of magnitude of those. And then there are more speculative things like the robots-first approach to going to Mars, which is one I'm personally a fan of.

So the question is have you gone through those exercises to get even a broad range of cost estimates for that? Because I think it's very destructive to an organization, you know, in my experience managing things to give a group of people orders that are impossible to execute. And I view going to Mars on a flat budget as an example of that. And so in order to make sure we have a consistent overall plan here, I think it would be very valuable to even have a very broad range of cost estimates for different things that tells you, among other things, how aggressively you should pursue new technologies if that's the only way you can get to a plausible budget. And so I was wondering, have you gone through those exercises even in rough terms for—if you had to write down the plan today with today's technology and with specific technological innovations, what are the rough cost estimates for our manned mission to Mars?

Mr. LIGHTFOOT. Yes, so we've kind of come at it from a different direction, so let me push on this. We've looked at this as what's—we're not expecting an Apollo-like injection of funds, right, so what we told our teams is just you need to assume what we call current services, which is basically our baseline budget that we have today plus a rate. And what we've talked about is—we call it the "and" proposition. It's not just the heavy lift, it's not just infrastructure, it's not just public-private partnerships. It's all that.

It's also not just robotic or human; it's both, right? Think about it. We're on Mars today with rovers, and you know that all too well. And the next rover that's going in 2020 is actually part of our human spaceflight planning because we've put an instrument on there to allow us to see if we can actually pull oxygen out of the atmosphere.

So what we've been doing for the past couple years is really integrating the science and human missions to say that any time we go anywhere is an opportunity for both sides, human or science, to actually get a benefit out of it instead of stovepiping the way we're thinking about that. So it's a sustainable process. And where we've come from is—or the way we've been approaching it is assume what you have today and then let's see where the technologies come in, where does private industry coming in? I mean, you see a lot of folks that really want—are really bringing systems into play in the private world.

Our international partners, we are engaging with our international partners on what they can bring because we think going to Mars with humans is going to be—is definitely going to be a global effort. Is not going to be just us. We'd love to lead it. We want to lead it and we are leading it, but we've met with the international partners twice now since I've been in this role and looking at their niche areas to come forward like they did for the International Space Station.

So that's how we've done it so far. When we bring the plan in in—there's a plan I think we're deliverable here in December—you'll see the pieces of that that come back——

Mr. FOSTER. Will that include a zero-order cost estimate for the whole endeavor with a given target date?

Mr. LIGHTFOOT. Yes, we'll——

Mr. FOSTER. I think that's fundamental to—you know, we have to plan——

Mr. LIGHTFOOT. Yes.

Mr. FOSTER. —how to convince the public to write a great big check to do this. And so we need a zero-order cost estimate. And also, as I mentioned, it's fundamental to the choice of technologies you are developing.

Mr. LIGHTFOOT. Absolutely. And we have for those technologies, but it'll come in. And again, our cost estimate will be based—it won't be we need this. It'll be based on this. This is what we think we can do and when. So, I mean, that's what you'll see.

Mr. FOSTER. Yes, and you mentioned escalation. In my experience managing technical projects, that's—inflation for technical projects was—generally ran above CBI inflation. And what number do you actually use internally for that?

Mr. LIGHTFOOT. We've been using 2.3.

Mr. FOSTER. All right.

Mr. LIGHTFOOT. Yes.

Mr. FOSTER. Okay.

Mr. LIGHTFOOT. But we've also I think—real quick, and I know we're over on time, but one thing I want to add is if you look at the GAO report recently on high-risk projects, we've actually gotten—we've actually shown improvement. We're not going to break our arms patting ourselves on the back here, but we've shown a tremendous amount of movement with our program project techniques and estimates that we've done and within the agency to actually be better at predicting the performance of these things going forward using a lot of lessons learned. We've had some—for some issues that we've had in the past, so I feel pretty confident that we can bring a number that we can stand behind.

Mr. FOSTER. All right. Thank you.

Chairman BABIN. Thank you very much. I'd now like to recognize the gentleman from California, Mr. Knight.

Mr. KNIGHT. Thank you, Mr. Chairman.

Thank you, Administrator, for being here.

You know, I'm going to talk about the big A because I always do. There are several things that are happening today, and I appreciate everyone talking about space exploration, and I wish Congressman Perlmutter was here so he could raise up his bumper sticker saying 2033. And all those are great and laudable goals, but

we are doing great things that are near-term and can change our economy.

You brought up the low boom supersonic demonstrator. I think there is probably nothing bigger that's happening right now for our near-term that could change our economy. And remember, as you know, for the last 60-plus years we've been flying across the country at .8 Mach, and we've been doing it a lot safer and economical, and we have been doing everything to make engines cleaner and all of that. But now, it's time to go faster. Let's get across the country faster. And I think the low boom supersonic demonstrator is that key that will get us there very quickly. Also, the X–57 is now moving very quickly into its stage of maybe changing flight over the future and making that a lot cleaner and maybe for the folks to get an airplane in their yard.

But one of the things I wanted to bring up is the education budget because education to me for NASA is accomplishments. If you show something to that 8-year-old, that 8-year-old wants to be an astronaut. There is no doubt about it. If you give him a coloring book, they might, but if you show them something, they will. There's no doubt. So as I think that education is a huge part of what NASA does, the more accomplishments you do, the more you're going to get. And I think that is a good indicator of what the Chairman brought up of how many people we've got applying to be an astronaut today is just because they want to be involved. And also what's been happening with Hubble over the last couple days have been huge accomplishments. So that's just my advertisement for what NASA is doing, and I thank you.

So my questions are more about aeronautics. The budget has changed. We think that the budget is going in a better direction for aeronautics, but it is still a very, very small part of the NASA budget, and so we're still under four percent. I think we're at about 3.6, somewhere in that range. Do you see that as a good spot? And it could be as a good spot for where aeronautics could be or should be. Or some of these programs that we could bring on board that could be funded by NASA, do you think that may be a little bit more money into aeronautics could get us there?

Mr. LIGHTFOOT. Yes, I think with the goals we have, New Aviation Horizons, for instance, that our aeronautics team has laid out which has so many fascinating, exciting missions in there, I think when you look at what we're trying to do with low boom, as you said, with X–57, just getting our teams back into the business of X-planes again has just reenergized them in a big way.

And we think this budget is actually pretty good for us for '18. We'll look and see what kind of energy we get around low boom, and we'll look at future—potential future—should we accelerate other things, but when you want to tap into a $2.5 trillion global economy, you know, of aviation, the U.S. needs to be in the middle of that, and our researchers are ready to go to that and I think that's what we're going to be doing. So I'm excited about what the guys have done from an aeronautics perspective. You know it just as well as I do because I know you meet with the guys a lot.

And I think the energy—we talk about the energy around human spaceflight. The energy around having an X-plane program is just enormous. It doesn't get spouted as much because it's not human

spaceflight, but when you talk to our teams, you know, the ones at Armstrong in particular, they've been beating on me for five years to get some X-planes——

Mr. KNIGHT. Good.

Mr. LIGHTFOOT. —so we finally got one, and so they're excited.

Mr. KNIGHT. And I appreciate you, you've been a good voice and a good leader in that aspect, and I appreciate that.

And then the last thing I'd like to talk about is NASA as a whole, we've kind of looked at everything that's happening, whether it be James Webb, whether it be our space exploration, whether it be aeronautics. Do you see that as a very healthy position right now, in other words, from the budget standpoint? Because I know the Chairman of this Subcommittee and the Chairman of the complete Committee on Science, Space, and Technology will always talk about the budget and where we are, are we healthy moving forward, are we accomplishing the goals? Because now, we're into a different realm over these last few years where the public is doing a lot of these things. They're doing low-Earth orbits, they're doing things that NASA kind of paved the way so that they could do it, but now they're taking over some of the things that NASA maybe doesn't do or doesn't have to do. So are we healthily moving forward?

Mr. LIGHTFOOT. I think we've got a good balance. I think—and I think we're doing it with a risk management process that allows us to understand that balance in a good way. You know, it's exciting to see American industry be so interested in the innovation that comes with that because that's what makes this country great, right, the American innovation that comes in. We can enable that, and then what we're trying to do is decide where that line is where we need to own it and we'd let industry take off. And I think we're still learning that, but I think we're at a good balance. I feel very comfortable with the balance we have right now.

Mr. KNIGHT. Very good. And I appreciate your leadership.

Mr. LIGHTFOOT. Thank you.

Chairman SMITH. Would the gentleman from California yield for a minute?

Mr. KNIGHT. I will. I don't have any time, but I will yield to the Chairman.

Chairman SMITH. I thought I'd point out for fun since we're among friends today something that not many people know about you, and that is that Congressman Knight has a special interest in space, particularly speed and space, which was indicated by his first question because his father set the record for speed that lasted, I think, for several decades——

Mr. KNIGHT. Still——

Chairman SMITH. —as—still——

Mr. KNIGHT. —50 years ago this year.

Chairman SMITH. Oh, my gosh, 50-year record and counting then as far as the speed of a manned aircraft. So we appreciate Congressman Knight being on the Committee and particularly his personal interest in this subject.

And I'll yield back.

Mr. KNIGHT. Thank you.

Mr. BRIDENSTINE. [Presiding] And I would second those comments, Mr. Chairman. Pete Knight is a hero to many of those of us who fly.

So I'd now like to recognize the gentleman from Louisiana, Mr. Abraham.

Mr. ABRAHAM. Thank you, Mr. Chairman. And let's continue the speed discussion and talk a little bit about hypersonics. Of all the things that we have to worry about for national security, we seem to be focused now, rightly so, on ballistic missiles of North Korea, Iran, those nefarious countries that want to do us harm evidently. But hypersonics are the weapon of not just the future but they're weapons of now. And I know NASA has some great research going on with the X–43 and other X-planes that will become critically important for national security because, unfortunately at this point, we can't intercept a hypersonic vehicle like we can a ballistic missile. So if you'll expound on that a little bit as NASA's roles in hypersonics and national security issues, please.

Mr. LIGHTFOOT. Yes. I think what we do in hypersonics, it's—for us, the part of hypersonics we're very interested in and we think we have the skill set to support from a national perspective is kind of the fundamental research where there's materials, where there's guidance, navigation, and control, propulsion, those kinds of areas that are basic in our—kind of our capabilities we have. And then there's a piece of it called the systems analysis where you can do the analysis around all those as a—when they become a system. It becomes a flight demonstration system. So that's where NASA's strengths are in hypersonics. We have some facilities that are very unique, and we have people that operate those that clearly have the intellectual capacity to understand all the history there.

So what we've done is we've partnered with DARPA and DOD in that area, and so what we do is we help them from just a fundamental research perspective, bringing the systems analysis in, and we think we're a part of their team. They've been very open to having us participate with them, and so I think that's where we think we bring—we bring to bear in that particular situation. Their job is the military side of that. Our job is the fundamental research.

And the reason we're interested—I want to be real clear. The reason we're interested is because at some point down the road you could actually potentially use hypersonic technology for—to get to orbit, right?

Mr. ABRAHAM. And to explore——

Mr. LIGHTFOOT. Absolutely.

Mr. ABRAHAM. —where we can't go yet——

Mr. LIGHTFOOT. Yes.

Mr. ABRAHAM. —literally Star Trek-type technology. And you alluded to it a little bit with the intellect. We all in this room certainly understand that NASA has always employed the best and the brightest. What is NASA doing to continue that evolution of pulling those students and those young people in so that we can stay ahead of our competitors and near peers in the global security world?

Mr. LIGHTFOOT. I think what—well, several things. We have several programs I mentioned earlier that each mission directorate has, whether it's Science STEM activation, whether it's the univer-

sity activities that Aeronautics is doing. Space Technology has graduate fellowships that they do—or research fellowships that they do. So that's the direct piece of it.

The other thing that we're doing I think is really important is we're taking a hard look at the capabilities we think we should be stewards for for the nation, whether it's propulsion, mechanical systems, you know, guidance navigation control, materials. Where do we need on that and where does industry have that that we can go take advantage of? And so we've spent the last couple of years really saying these are the technical capabilities we should be stewards of.

Mr. ABRAHAM. Are you guys actively recruiting in the universities——

Mr. LIGHTFOOT. Oh, yeah.

Mr. ABRAHAM. —or are you waiting for the students to collect the 18,000 applicants for 12 slots of astronauts?

Mr. LIGHTFOOT. No, we are actively recruiting. We don't have—that is an area where we do not have a challenge. We get a ton of applications—and you heard 18,000 for astronauts. We get a lot for any engineering position that pops up. And we are—we—our brand does well in the universities, and so we're pretty successful there.

Mr. ABRAHAM. And we're glad it does, I assure you.

One last question. Previously, we in this Committee have been told that I think maybe 80 percent of NASA's infrastructure is beyond design life. And I'm assuming that's still true considering that the budget has remained fairly flat. How critical is that right now?

Mr. LIGHTFOOT. Well, we—it's pretty critical, and what we've done is we've put in place a pretty extensive process to look at duplication and overlap in facilities and capabilities to make sure when we give you that number that that number is not a bunch of the same stuff, right? And so we've spent the last three years going through that and defining what the center role should be so that we know where to target to get out of some of the older infrastructure that we have, and we've been very successful in that so far.

So the teams are doing a good job depending on each other. Instead of being nine different centers across the United States, we're an integrated system. And so that's what we're trying to do to get that down. We won't—the biggest way to get rid of the backlog of maintenance is to tear the old stuff down and build new stuff, right? And so that's the way we're looking at it, and we're actually being very strategic about how we go doing that—

Mr. ABRAHAM. Good.

Mr. LIGHTFOOT. —in terms of attacking the higher-maintenance things first.

Mr. ABRAHAM. Thank you. We appreciate NASA.

Mr. LIGHTFOOT. Thank you.

Mr. ABRAHAM. I yield back.

Mr. BRIDENSTINE. The gentleman from Florida, Mr. Dunn, is recognized.

Mr. DUNN. Thank you very much, Mr. Chairman, and thank you, Mr. Lightfoot, for being here.

Let me, if I can, stay on the subjects of aeronautics, science, and strategy just a bit. We've had a lot of talk about the Deep Space Gateway. Can you elaborate a little bit on how that impacts the strategy for our country going forward and maybe discuss just a little bit for everybody how that works?

Mr. LIGHTFOOT. Yes. So when we talk about leaving low-Earth orbit, we think we need an infrastructure, kind of a backbone that allows us to do that. So what we've been looking at is a way to very affordably—not a large system that we have to maintain, to the earlier question. What are the—what is the actual minimum capability we need around the Moon to allow us to start testing these systems out?

So what—we talk about a gateway, we talk about an infrastructure, and it's in the concept phase. We still—we're still working with the Administration on what that will look like at the end of the day. But we believe it includes a power propulsion unit that'll be built off of what we did for the ARM mission, Asteroid Retrieval Mission. We think we'll have a habitat. We're working right now with five different potential vendors on our NextSTEP BAAs to do habitat systems, habitat concepts. And then we'll have an airlock on there, and you'll be able to move this around and you can operate telerobotically on the Moon. You can use it as a place that you actually take off and go to Mars from there with a different system. It's almost a node if you want to call it that. So—

Mr. DUNN. Does it impact cislunar missions as well?

Mr. LIGHTFOOT. Oh, yes, absolutely. It would allow us to move around the Moon and do multiple types of missions around there.

Mr. DUNN. All right. Thank you very much. So what other countries are in that space besides us?

Mr. LIGHTFOOT. In the cislunar space?

Mr. DUNN. Yes.

Mr. LIGHTFOOT. Right now, no one's there—the Chinese. I should say the Chinese are going to the Moon; we know that. But what we've been doing is we've been talking to all our international partners, the same ones we have on the International Space Station today, about where they would like to participate in those exploration plans as we go forward. So we continue to share with them what we're thinking, and they bring in their niche areas that would be good for them. They actually bring—I mean, several of them bring very good capabilities to us.

And so as we look at a global effort in a resource-constrained environment, you know, those partnerships, whether they're international or whether they're public-private here in the United States, are all for us things that we can use.

Mr. DUNN. And last, I'd like to ask you to talk a little bit about the CubeSats that have become so popular, the smaller mission satellites and the launching clusters. And I know we're now assembling those on the Cape——

Mr. LIGHTFOOT. Right.

Mr. DUNN. —in the center, and maybe talk to us a little bit about how NASA is going to be interacting in that space.

Mr. LIGHTFOOT. Yes, this is an exciting area I think, a very exciting area. As CubeSats have gotten—CubeSats and SmallSats have gotten—we got—we're able to control them better. We're able to get

actual science data. We're actually using them for communications. It's a very interesting area. We have an initiative in this budget that does—a SmallSat/CubeSat initiative. Their science is actually going to look at a way to get some of the data that we've been getting with big missions. Can you actually get the same kind of data, close data from a capability perspective using CubeSats because we can launch them as part of another mission, right? You've seen that. We take them up to space station and we launch them from the space station out of the Japanese module.

So we're learning more and more about that, and we're also getting better with the systems. I mean, the systems are getting smaller and smaller. It's amazing what you can do with these CubeSats now in terms of controlling their attitude and propulsive maneuvers on orbit. So that's what we—we think that's a big opportunity for us, and that's why it's in the science budget this year to—

Mr. DUNN. And are those CubeSats, are they hardened in an EMP sense, are they hardening and stuff?

Mr. LIGHTFOOT. Oh, I don't know. I don't think we've gotten that far yet to think about that but—

Mr. DUNN. That's your task.

Mr. LIGHTFOOT. Yes.

Mr. DUNN. Thank you very much, Mr. Lightfoot. I enjoyed your testimony.

Mr. LIGHTFOOT. Thank you.

Mr. DUNN. Mr. Chairman, I yield back.

Mr. POSEY. [Presiding] The Chair recognizes the gentleman from Indiana, Mr. Banks.

Mr. BANKS. Thank you, Mr. Chairman.

And, Administer Lightfoot, just a brief statement, not a question for you this morning. My district in northeast Indiana is one of the largest manufacturing districts in the entire country, building everything from RVs to military hardware. We have some companies as well that specifically support NASA programs, including the designing and building of sophisticated satellite payloads for national and international weather observations.

One specific program important in my district is called the Radiation Budget Instrument. It will leapfrog current technology by accurately measuring the impact of the Sun's energy on the Earth and the Earth's own energy than the current generation of sensors that we currently utilize. The technology advances are critical to researchers to help improve longer-term and seasonal weather forecasting, such as seasonal tornado and hurricane forecasts. There are many parts of the country, including Indiana, which will benefit from these breakthrough technologies.

I understand the agency must make priority calls, but it is my understanding that the program is 80 percent complete, is on track for an on-time delivery, and has solved all major technical challenges. Looking forward during the budget process, I would like to work with you and my colleagues to ensure that we don't discard investments that we've already made in these next-generation technologies and lose the opportunity for greatly increased seasonal forecasting, which will help our emergency managers, and in our agriculture and energy sectors, among many others.

So I look forward to working with you and having those discussions in the future. I appreciate your testimony today.

With that, Mr. Chairman, I yield back.

Mr. POSEY. The Chair will now recognize himself for five minutes.

Mr. Lightfoot, I've heard that there might be some challenges at KSC due to a shortfall of funding for ground systems. Could you comment on that for me, please?

Mr. LIGHTFOOT. I think ground systems is okay from a perspective of what they're trying to do. We have some of the money that normally would be in the ground systems budget is actually in the construction budget. When you add them together, it's the money they need to get the job done.

Mr. POSEY. Okay. We both know that if everything's a priority, then nothing's a priority, and so I'm curious about a roadmap to Mars and our ability to stick to that roadmap, subject to funding of course.

Mr. LIGHTFOOT. Well, I think—I mean, we have a report due back I think to this Committee in December 1 that's going to show the plan. I believe we were asked to provide a plan of getting to Mars by 2033. And so we're working on that, and I think you'll see why we think it's actually a sustainable plan based on the budget that we've got. So I think if you look at the series of missions we're planning on doing in the 2020s with the SLS Orion combination, the missions we're talking about doing with our commercial partners to actually, you know, provide the supplies for what we're trying to do, I think you'll see that there's—it's a sustainable plan and it's actually doable if we had—to your point, if we'll just stick with it.

Mr. POSEY. Okay. If you had one percent of our budget instead of just a half a percent or if you could have like four percent during Apollo or something, what would you do?

Mr. LIGHTFOOT. Wow. I think what—so I think the way I would answer that question is that you see what we do today with the budget that we get——

Mr. POSEY. Yes.

Mr. LIGHTFOOT. —right? And I think you would just see more contributions to the scientific discovery, the exploration, the pushing humans further into space. But I also recognize that we're part of bigger federal budget here, and I think that balance has to be maintained. And, you know, that's for—to me, that's for you guys to decide where that balance is for us.

Could we do more? Sure, we could do more, but within the other constraints we have as a nation, you know, that to me is—I think we have a good budget for what we need to go do.

Mr. POSEY. Okay. Could you comment on the Administration's decision not to put crew on the first flight?

Mr. LIGHTFOOT. Yes, sir. I—as I said earlier, I think that was as much our decision as it was theirs. We worked with them directly on that. We just felt that the addition of the technical risk, the addition of the cost risk, and the addition of the schedule risk actually showed that our plan was—that we had to start with was actually probably the right one and the right way to go. And I think to me it was—it was a—when we got—when the teams brought all

the information, as excited as we were about possibly doing it, it actually confirmed we should be doing what we're doing from an overall perspective.

Mr. POSEY. It hasn't been very clear in the press, but, you know, China has been quite active on the Moon, and I wonder if you'd comment on that.

Mr. LIGHTFOOT. Well, I think the Chinese have—you know, I know as much as you do from a press perspective, but you can see there—they've got their first piece of what would be their space station on orbit now. They've gone to the Moon. They're talking about going again. They've made some announcement this week about that in terms of a sample type return from the Moon. So they're very active.

You know, I think, you know, for us we have to decide some—at some point what's going to be our interaction with them from an overall perspective as a Federal Government, how we're going to deal with them. Their—the stuff we've worked with them on has been mostly scientific in nature going forward, and I think we just should keep paying attention to what they're doing and make sure we're not ceding leadership from that perspective.

Mr. POSEY. I think that's very important. Do you see any militarization of the Moon by the Chinese?

Mr. LIGHTFOOT. I don't. That's probably for somebody else to answer so I haven't—not in my world.

Mr. POSEY. Do you think we're still ahead of them on efforts to go to the Moon again?

Mr. LIGHTFOOT. I think so. I think the systems that were put in place are—I think we are, but I don't have any insight into their systems as much as I do ours, so I'm pretty confident in our ability to do what we want to go do, and I think that's where we—I think we're okay from that standpoint.

Mr. POSEY. Okay. Thank you very much, Mr. Lightfoot.

Mr. LIGHTFOOT. Thank you.

Mr. POSEY. The Chair recognizes the gentleman from Louisiana, Mr. Higgins.

Mr. HIGGINS. Thank you, Mr. Chairman.

Mr. Lightfoot, thank you very much for being here. This is fascinating conversation. I was born in 1961. I have a very nostalgic memory of NASA as I grew as a young lad and observed the Moon landing, and for my entire life I've looked forward to our return to space and our return to dominance in space, which we certainly seem to have lost that clear dominance as a nation as we explore beyond our planet.

The history of NASA is replete with the smartest guys and women in the world, doing more with less, and I'm happy to say that the current budget, as requested by the President, cuts NASA's budget, it's the lowest of any nondefense or non-security-related part of the executive. And because this is a discussion about budget and NASA and what you can do and we recognize that, certainly on this Committee from a bipartisan perspective, we recognize that if we're to be first on Earth, we must be first in space, and yet we must protect the people's Treasury.

One of the projects that I've followed through the years which is a fascinating success is Cassini. In your written testimony you stat-

ed that after 13 years orbiting Saturn our Cassini spacecraft has begun a series of 22 daring dives through the 1,500-mile-wide gap between the planet and its rings as part of the mission's grand finale. That'll be in September of this year, 19 years from launch. This mission also included a lander on Titan, Saturn's largest moon, which sent back fascinating data. And it's important to note that the success of Cassini and the Titan lander was reflective of 25- to 30-year-old technology, 1980s and early '90s technology.

So my question to you would be considering the fact that this technology and the success of Cassini is that old, is predigital—we should note that the iPhone was introduced in 2004—what do you expect from Cassini's September end-of-mission controlled crash into the surface of Saturn, and what might we expect from missions developed with current technologies as we move forward and as that relates to NASA's historic ability to do more with less?

Mr. LIGHTFOOT. Yes, I think—so I've gotten—I've been in this business long enough and in this agency long enough to not speculate on what we might see because we always get surprised with what we learn. If you look at the recent images from Juno that went around Jupiter, I mean, just stunning.

Mr. HIGGINS. Right.

Mr. LIGHTFOOT. And that's newer technology still, you know, when we launch a missile, a little older, but I think what you'll see with Cassini is—this is why we're doing the dives. We want to see what's there, what's in there. We've already learned even from some of the initial passes. To me what's happened, the reason we're able to do more with less is because of the advances in technology, right? If you look at the miniaturization—like you said, your iPhone—if you look at the miniaturization of sensors, propulsion systems, all the things that are happening, you try to pack those into a spacecraft that's going to go make these incredible discoveries, that miniaturization actually helps us, right? It helps us to be able to build these spacecraft because they're—to get them off Earth is the hardest part of this, you know, getting there.

So I think the technologies we're working on, whether they're new detectors, new sensors, that's what we have in our budget from a science standpoint and the technology standpoint. Both of those mission directorates are working on those kind of things to allow us to get that even better kind of data that we get. New Horizons is another great example of when it went by Pluto and did stuff that we got back there. So technology is a critical piece of this. That's why we think the Space Technology Mission Directorate and the technology that the Science Mission Directorate does is actually beats forward into the next mission. The starshade, for instance, that I talked about earlier is another technology we'd love to get on orbit and again be able to use those technologies to just do better discoveries and more discoveries.

The thing that I've learned is every question we answer causes more questions, right, and that's what's so exciting about what we do from a science standpoint. And that technology helps us to actually move forward.

Mr. HIGGINS. Thank you for that answer. Just briefly, could you address regarding the budget as it currently begins to manifest for

NASA, what's the general morale within NASA? It seems to be an exciting time of rebirth. And please address that briefly.

Mr. LIGHTFOOT. Yes. You know, we're the best place to work in government for the last five years, and I think that probably says it the best. That's our workforce filling out the governmentwide survey. People are excited. I mean, the Chairman was there yesterday at Johnson. Goodness gracious, people were just—it's—they're excited about what we're doing, and they're excited because we're—if you look at the cadence of discoveries—we make a lot of news, right, and it's usually good news, you know, usually. And I think that inspires our teams to actually do even more. So, yes, I think the morale is good, very good.

Mr. HIGGINS. Thank you very much. Mr. Chairman, I yield back.

Chairman BABIN. Thank you.

I now recognize the gentleman from Florida, Mr. Webster.

Mr. WEBSTER. Thank you, Mr. Chair.

Mr. Posey was asking about the money constraints, and you laid out a time frame of how you could work out a trip to Mars. Isn't that also constrained by timing? It seemed like we had testimony before about the fact that there are certain good times and they come around not so often.

Mr. LIGHTFOOT. Yes, there is a—it's a—you look at 2031, 2033, for instance, they are very good times for us to go to Mars based on the orbital mechanics of where Mars is located and where the Earth is so——

Mr. PERLMUTTER. I just like '23.

Mr. LIGHTFOOT. I know. I almost brought the bumper sticker, sir. Anyway—but I do think that there are more optimal times because the crew transit time, if you have crew, you want to take those shorter—that's why 2033 is probably one of the—I think it's a nine-month transit—I probably got that wrong but that's what we're looking at.

Mr. WEBSTER. You mentioned nodes, and are there ways that we can advantage ourselves with those nodes in other places like the Moon and maybe launch from there? Does that change any of that?

Mr. LIGHTFOOT. Yes, that's one reason we're looking at that, that kind of gateway concept that I talked about. It would be a place where you can actually operate down at the Moon if you wanted to, but you can also take whatever system you want to take to Mars and launch from that location.

Mr. WEBSTER. So wherever you get to, you're advantaged by the fact you're there as opposed to having everything in one hub, which would be the Earth.

Mr. LIGHTFOOT. And you go—with the way we look at it is you go back and forth from that node to Mars, and then you come from that node home with a different system so——

Mr. WEBSTER. Would the funding that you have proposed or you're going to share and the timescale and all of that, would that include taking stuff with you?

Mr. LIGHTFOOT. Taking stuff?

Mr. WEBSTER. Okay. So let's say it's 2033, and you're saying if you were to launch from there, from that node, isn't your plan not only to get there but also take things that would facilitate a future launch maybe from there?

Mr. LIGHTFOOT. Yes, that's the goal, right, would be to set that infrastructure up so that you can go do that. But we're also looking at ways that we can live off the land when we get there. It's called in situ resource utilization. Today on the International Space Station we process all that moisture into water that these guys can drink so I don't have to carry it. Water is pretty heavy. I don't have to take it with me.

We've also been doing 3–D printing in space. We have a 3–D printer on the International Space Station that we're thinking is kind of a precursor to what you might take with you when you go. And if something breaks——

Mr. WEBSTER. Can you manufacture things there?

Mr. LIGHTFOOT. You can do your part—we're doing parts today on station using the powders that we've got. So it's pretty exciting from that standpoint. That's the kind of way we're looking at it, so it's going to be a combination of what do we need to take but what can we also have with us?

Mr. WEBSTER. And I guess that advances as technology moves forward?

Mr. LIGHTFOOT. Oh, yes. Oh, yes.

Mr. WEBSTER. Great. I yield back. Thank you.

Chairman BABIN. Thank you so much. That's fascinating.

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

Mr. PERLMUTTER. Mr. Lightfoot, as always, it was music to my ears to hear about 2031, '32, '33. So let's just remember we can do this and we will do this. And I know that a lot of the morale is high because you really are beginning to, you know, really expand your reach and go farther and put all that talent that you have within NASA really to work on so many different, you know, exciting projects. So thank you for that.

So how are we doing budgetarily in terms of putting the pieces together to get us to Mars by 2033?

Mr. LIGHTFOOT. Yes. I think the '18 budget that we've proposed here actually keeps the progress going——

Mr. PERLMUTTER. Okay.

Mr. LIGHTFOOT. —on what we need to do to do that. For us, the process is pretty simple. It's use the International Space Station to the maximum extent possible to develop those systems. That really is our jumping-off point. We're putting systems up there now. We've got Bigelow up there that, you know, is an expandable module. We have technologies we're taking up there constantly that we think will be used for future parts of this. And then we're doing the human research that we need to understand what happens to the human body, right? So we just—the data coming back from that is going to actually help us with—as we take these longer missions to Mars.

And then we think we—then, we're going to establish some infrastructure around the Moon in cislunar space, and then that will be our jumping off point as we start going to Mars. So that—this—the '18 budget continues those systems. We think we're pretty confident in that.

Mr. PERLMUTTER. Good. Are you working with outside companies, with other nations? How's that going?

Mr. LIGHTFOOT. Yes. We—so let's start with—we think there's a lot of opportunity for public-private partnerships. We do—we've seen a great deal of interest from a lot of the industry in this country and how they want to participate and where they're going to bring things to bear for us. So that's been very positive, kind of building off what we do with commercial cargo and commercial crew, right——

Mr. PERLMUTTER. Good.

Mr. LIGHTFOOT. —using that model. The other piece is the international piece. We've had several—as mentioned earlier, I've had a couple of heads-of-agency meetings with my counterparts internationally. Mostly the ones that we deal with on the International Space Station, they're very interested in participating with us on this journey. It's going to be a global journey; we know that. And I think—because when we get there, that's going to be a civilization-level impact, right, just like when we landed on the Moon. And I think that's the—to me, that's going to be a we did it, we as a globe, you know, not just the United States, not just NASA. And I think that's what we're going to have to do. But we've got a ton of interest from them as well.

Mr. PERLMUTTER. All right. So let me switch to a couple smaller programs that are particularly important to Colorado. NEOCam, something that we had talked about earlier that—I was looking for it in the budget but I'm not sure that I saw it in there. Can you tell us about NEOCam and where you are?

Mr. LIGHTFOOT. Yes, so we—NEOCam was part of a recent set of selections, and what we decided to do was we were interested in the technology associated with NEOCam. It went a little bit further than we thought we needed from a planetary defense perspective, so we've asked them to go back and say, okay, if you—just as a planetary defense satellite, could you do this? We continue to identify the potential hazards, asteroids, you know, in this—that we're required to go do.

We think NEOCam is a tool we could actually bring to bear, but it had a science piece in it that we really wanted to go back to use the planetary defense from a focus standpoint. So we've kept the guys going to develop that technology, come back, and we expect to hear—I think in about a year they're coming back from a formulation perspective to tell us where they are. And it can be a tool that gets added to our tool chest because we think there's also other ways to do it may be with a SmallSat, something like that to get the same data.

Mr. PERLMUTTER. Okay. And then—I mean, so it'll fall in the planetary defense category, but even at some point maybe we put some science money into it, too, if that were——

Mr. LIGHTFOOT. Well, the planetary defense budget is in science so that's good.

Mr. PERLMUTTER. But, I mean, you've got certain categories that fit nicely in that one so let's just make sure we keep pursuing that.

The last one—last question I have is on CLARREO, which University of Colorado is very interested in. And I think it was taken out of the budget. Can you explain that, please?

Mr. LIGHTFOOT. Yes, the CLARREO Pathfinder mission——

Mr. PERLMUTTER. Yes.

Mr. LIGHTFOOT. —which was going to fly on the International Space Station, that was some precursor work we were doing associated with a bigger CLARREO mission. The CLARREO mission—the bigger mission estimated out about $1 billion overall. So what we wanted to do was we wanted to wait until the decadal was done. There's a decadal in 2017 for science to see where—while that ranked—while the bigger mission—not the Pathfinder mission but the bigger mission ranked on the 2007 decadal, we wanted to see what would happen on the 2017 decadal, and so that's why we did what we did. That was choice we made before we made that next big investment.

Mr. PERLMUTTER. So we'll know over the course of next year?

Mr. LIGHTFOOT. Yes, well, we're canceling Pathfinder. We've proposed to terminate Pathfinder.

Mr. PERLMUTTER. Okay.

Mr. LIGHTFOOT. And what we'll do is when the next decadal will come out, we'll see where those particular science objectives—where they rate and relook at the whole portfolio from earth science.

Mr. PERLMUTTER. All right. Thank you for your testimony and thank you for your service.

Mr. LIGHTFOOT. Thank you.

Chairman BABIN. Thank you.

And now I recognize the gentleman from California, Mr. Rohrabacher.

Mr. ROHRABACHER. Thank you very much, Mr. Chairman, and I apologize, going back and forth between hearings, so if I ask a repetitive question, I apologize.

We just heard that we are spending money for the tracking and characterization of near-Earth objects. Is there anything in place if we do discover a near-Earth object heading towards us, do we have a procedure in place that would then be activated in order to some way deflect that near-Earth object if it threatens the planet?

Mr. LIGHTFOOT. We don't have anything that we're building to deflect it at this point. We've got a defense coordination office, you know, that does all the notifications to everyone if we see something coming, but I don't—I mean, we'd have to see what we would do after—at that point. We're not building anything related to that.

Mr. ROHRABACHER. Okay. I would suggest, Mr. Chairman, one of the things we need to do is to insist that we actually have—if a near-Earth object is spotted coming to the Earth, could kill millions of people, if not even worse—that we should demand someone, whether it's NASA or whoever, to actually have a system where you say punch the red button, it's time to go on this particular emergency. We need to do that.

Now, let me ask you about space debris. We know that we've got—there's lots of examples. I mean, the debris shield, was it last March it had floated away from the space station. It was a debris shield, so we know that debris is actually causing some problems already. We know the space shuttle was postponed a couple times for space debris accumulation. Do we have anything in place where we have planned that will in some way deal with that problem meaning to remove space debris?

Mr. LIGHTFOOT. Yes, this—so obviously, micrometeorite debris and other debris up there is actually our number-one risk for our human spaceflight mission in terms of——

Mr. ROHRABACHER. Right.

Mr. LIGHTFOOT. —the area where they are. And we—so we track it. We have a great system for tracking it, as you would say.

Mr. ROHRABACHER. Right. All right. But——

Mr. LIGHTFOOT. But what we've been working on in the agency is simply—we haven't worked on these systems to get removed; we've been working on some of the technologies that might be able to do it, but it's a very low-level effort. I don't want to imply that it's a big effort——

Mr. ROHRABACHER. Yeah.

Mr. LIGHTFOOT. —but that's what we've been doing.

Mr. ROHRABACHER. I would suggest that it threatens the viability of our entire system. By the way, what is the—going to be the cost of the SLS rocket in the—per rocket?

Mr. LIGHTFOOT. Let me get back to you on that number. We just—only because we just finished an activity that they're briefing me on next month.

Mr. ROHRABACHER. Is it going to be over $1 billion or——

Mr. LIGHTFOOT. I haven't seen the number, sir, honestly so——

Mr. ROHRABACHER. All right. Okay. Well, let me just note that my guess, if we're spending several billion dollars a year now, that these rockets are going to be phenomenally expensive. I would hate to think of a little bit of space debris coming along and negating $2–3 billion worth of spending on an SLS rocket. So whether it's planetary defense, we ought to have a system in place. We ought to get serious about space debris before space debris starts hemming us in so much that it's put costly restrictions on our own space program. And I would think that this should be an international effort. And have we had any type of international meetings on space debris?

Mr. LIGHTFOOT. I think there's several things in place that we're required to do like de-orbiting second stages and things like that that are discussed internationally.

Mr. ROHRABACHER. But we haven't had a—some sort of a major meeting where people get together and say what can we do to clear space debris as an international effort?

Mr. LIGHTFOOT. And—not that I know of unless we've done something through the UN COPUOS stuff. I'd have to——

Mr. ROHRABACHER. All right.

Mr. LIGHTFOOT. But I'll get back with you on that one. I'll certainly take that one——

Mr. ROHRABACHER. All right.

Mr. LIGHTFOOT. —for the record and let you know.

Mr. ROHRABACHER. All right. And finally, let me just note about earth science. There are so many other people that can analyze what's going on in the Earth. I don't see any reason why we should—I love the Hubble telescopes and the various things that are aimed outward, but I have no reason to believe that people in NASA have any more expertise at trying to study what the Earth is about. They're supposed to be out studying what the universe is about, and I would think that we should, Mr. Chairman, move

away from funding of earth science missions and start focusing on the real mission of NASA, which is the missions we are aiming into space.

Thank you very much, Mr. Chairman.

Chairman BABIN. Thank you for that line of questioning.

Mr. Veasey, the gentleman from Texas, I call on you.

Mr. VEASEY. Thank you. Thank you very much.

And I wanted to ask a question about human space exploration. And under the funding level proposed for exploration habitation systems, when could NASA expect to have a habitation system operational for use on an exploration mission? And what will that habitat actually be used for?

Mr. LIGHTFOOT. Yes, so I think the way we're looking at now we've got a process in place called our NextSTEP BAAs that are looking at what habitation systems could be available for us from some—we've got five people that are—five different companies that are working that with us. The habitation model—module based on our current plans, you know, would fly roughly in the middle of the 2020s. It would be located somewhere around—or in the vicinity of the Moon so that we could actually use that area there going forward. It would have the systems in it. We would help outfit it with the systems that we would need for a longer-term journey so we can test the systems out there as well. So that's what we're looking at.

Mr. VEASEY. Okay. As far as the CASIS key accomplishments for this year regarding broadening the use of the ISS national laboratory, can you just go over some of the—what you think some of the key accomplishments are?

Mr. LIGHTFOOT. Well, I think CASIS has done a great job in terms of bringing some of the critical research, whether it's rodent research, you know, that we do to understand the effects of medications or space travel on rodents that I—the CASIS team has done a great job working with researchers there. They've been bringing different CubeSats up, different things that they're working on to give us more scientific data when we actually deploy from the International Space Station. They're just—they're continuing to really develop that market if you want to call it that, the people that can actually come up there, whether it's scientific research, medical research, or just the other deploying of CubeSats from the station. So they've done a really good job as a partner for us on that.

Mr. VEASEY. Oh, good. Good. What about progresses you think NASA has made in just helping, you know, retire and mitigate some key risks that are associated with human exploration in deep space?

Mr. LIGHTFOOT. Yes, I think the—to me that—those key risks kind of fall in two categories as the risk on the human and it's the risk on the systems that we need. So we're continuing to work in our Space Technology Mission Directorate on some of those key technologies, whether it's entry, descent, and landing, whether it's radiation protection, those kind of activities. On the station itself, we're utilizing the systems that we have. If you think we did—Scott Kelly did the one-year mission, right, to understand the impacts of somebody being on the station for year as opposed to six

months. So we've got a list of human research, things that we would like to do on the International Space Station before we start pushing out further, and we've got some technical things with life-support systems, radiation protection that we're working on. And we continue to work on those, and they're supported in this budget.

Mr. VEASEY. How do you think adding the fourth member aboard ISS will help mitigate some of those risks?

Mr. LIGHTFOOT. I'm super excited about that because we get—by having four members doing the research that we do, we expect to really increase the production, you know, because operating station takes some of their time. Now, we'll have somebody that can really be focused on the research. And we've got lots of research up there. Because of the resiliency of our transportation systems now with the commercial cargo guys, we're getting a lot of research up there for these guys to do. And so having an extra crewmember will be outstanding for that.

Mr. VEASEY. Do you think that NASA is confident that all of human exploration health risks will be retired before the ISS is decommissioned in 2024?

Mr. LIGHTFOOT. Well, all is a big word. I don't know if we'll ever have all our risks retired on anything we're doing. I think we will—the way we look at risk is we manage it. From a perspective of the critical ones, I think we will have—I don't think we'll have the critical risks retired, but we'll know what we need to do when we're in cislunar space to mitigate those risks going forward.

Mr. VEASEY. Okay. Thank you.

Thank you, Mr. Chairman. I yield back.

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

And I want to ask one quick question here, Mr. Lightfoot. Should NASA be responsible for regulating private sector planetary protection standards? What would you say about that?

Mr. LIGHTFOOT. I think we would like to be engaged in a conversation. I think we have some expertise that we can bring to bear there. I don't see us so much as a regulatory agency as one that should be consulted is the way I look at it.

Chairman BABIN. Yes. So that's kind of a yes?

Mr. LIGHTFOOT. Yes. Yes, I think as long as we're—we would love to play a consulting role in that particular activity.

Chairman BABIN. Okay. All right. Thank you very much.

I want to thank the witness today for his testimony, very valuable, very interesting, and thank the members for their very insightful and interesting questions as well.

The record will remain open for two weeks for additional comments and written questions from Members who may want to ask something additional.

So with that, this hearing is adjourned.

Mr. LIGHTFOOT. Thank you, Mr. Chairman.

Chairman BABIN. Yes, sir.

[Whereupon, at 11:42 p.m., the Subcommittee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Mr. Robert M. Lightfoot, Jr.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"An Overview of the National Aeronautics and Space Administration Budget for Fiscal Year 2018"

Mr. Robert M. Lightfoot, Jr., Acting Administrator, National Aeronautics and Space Administration (NASA)

Question submitted by Ranking Member Ami Bera, House Committee on Science, Space, and Technology

1. During the hearing, you testified that NASA is planning to have a habitat operating in cislunar space by the mid-2020s. What are the milestones that need to be met in order to have a cislunar habitat by the mid-2020s? Does the 5-year budget plan support such a development schedule, or will inflationary growth, at a minimum, be needed in the human exploration budget?

Answer: NASA is engaged with several commercial and international partners to advance and test a variety of habitation technologies and infrastructure options. The Next Space Technologies for Exploration Partnerships (NextSTEP) activity, plus related technology developments and partnerships, will enable deployment of an initial deep space habitation capability in the mid-2020s. The purpose of the NextSTEP Habitation development activity is to investigate leveraging U.S. industry capabilities that could enable NASA habitation needs from LEO commercialization activities all the way through development and testing of a Mars-class habitation system.

Currently in Phase 2 of this effort, NASA is developing habitation system concepts and technologies from six U.S. companies (Bigelow Aerospace, Boeing, Lockheed Martin, NanoRacks, Orbital ATK, Sierra Nevada Corp.) with the goal of developing full-size cislunar habitat ground prototypes by 2018. These ground prototypes will allow NASA and the NextSTEP habitation partners to: 1) evaluate configurations and habitability attributes of the habitat, 2) assess how the various systems interact together and with other capabilities like propulsion modules and airlocks, and 3) provide platforms to test and ensure that the standards and common interfaces being considered are comprehensive and enable the intended interoperability. Each of these activities will contribute to validating the systems needed for more challenging human future deep space activities.

Concurrently, NASA is assessing opportunities for international collaboration in developing cislunar habitation capabilities, including through leveraging current ISS and other partnerships.

The initial cislunar habitation capability can be configured differently depending on mission needs and though there are various concepts for configuration, current analysis has concluded that this habitation capability is composed of four functional capabilities: habitat, logistics module(s), airlock, and a power/propulsion bus. Progressing the commercial NextSTEP-2 activity, continuing with technology development, and continuing discussions

with potential international partners will all contribute to decision(s) on an acquisition approach for habitation for deep space and for commercial investment in LEO capability.

At this time, a cislunar "Gateway" is only a concept, and the activities described above, along with other considerations, will help inform whether NASA will pursue it in the 2020s. To support an operational cislunar Gateway in the mid-2020s, major milestones include the identification of functional allocations and requirements, the Gateway acquisition strategy (mid-2019), and Gateway elements delivered to Kennedy Space Center nine months prior to launch. Because development of the elements would be spread over several years, the funding estimates indicate that the President's FY 2018 Budget Request is supportive of these efforts. Whether there are additional needs to support a the concept by the mid 2020s is still being assessed, along with NASA's plans to pursue it moving forward.

For further information on NextSTEP, please access the following website: https://www.nasa.gov/nextstep

2. Under the Commercial Crew program, two U.S. companies are developing spacecraft to carry astronauts to and from the International Space Station (ISS). Under current plans, both providers are expected to complete certification of their systems during 2018. However, delays in the program led the GAO to recommend that NASA develop contingency plans in case the companies are not ready to launch U.S. astronauts.

   a. What is the confidence level that current planned dates for certification will be met by the Commercial Crew providers, and what are the factors most likely to disrupt this schedule?

      Answer: In general, recent delays associated with the partners' commercial crew contract schedules reflect normal development difficulties and technical challenges associated with human space transportation systems. The Commercial Crew Program is currently tracking specific technical and programmatic risks that could result in additional schedule delays. Two top programmatic risks are: difficulty in meeting the loss of crew requirement and aborting into sea states with unsafe rescue. Specific technical issues associated with the partner designs are proprietary, but non-proprietary status updates are provided at public meetings of the NASA Advisory Council (NAC) and NAC HEO Committee.

   b. What are the most difficult challenges that remain prior to successful certification?

      Answer: As noted above, recent delays associated with CCP contract schedules reflect normal development difficulties and technical challenges associated with human space transportation systems as our partners prepare to meet certification reviews and other milestones.

3. The FY 2018 budget provides support for a new Science Mission Directorate initiative that seeks to leverage small satellites to address some of NASA's high-priority science objectives.
    a. How does NASA plan to coordinate smallsat activities across the different Science divisions?

        Answer: NASA is formalizing a new Small Spacecraft Coordination Working Group (SSCWG), with membership from SMD, STMD, and HEO, to enhance coordination for all NASA small spacecraft activities. The SSCWG will identify high-priority science objectives, across Science Divisions and Mission Directorates, which can be addressed with CubeSats/SmallSats and conduct a strategic assessment to identify technology gaps and opportunities. This collaborative team will allow the divisions and directorates to expand capabilities with strategic investments while avoiding unnecessary duplication. SMD will also continue encouraging the miniaturization of instruments through its solicitation process, as it does now in projects across all four Science Divisions.

    b. Does NASA plan to partner with the commercial sector on this initiative? If so, how?

        Answer: SMD and STMD are actively engaged in pre-planning activities to establish new programs that would enable the use of public-private partnerships for these missions and will continue to work with our partners to take advantage of secondary/hosted payload opportunities on commercial launches. NASA intends to leverage and partner with the growing commercial sector to collaboratively drive instrument and sensor innovation. Given the pace at which these technologies are changing, we will have more frequent engagements with industry and the scientific community to gain insight and understanding into new and/or enhanced capabilities.

4. The FY 2018 budget request provides no funding for a Europa lander mission, despite legislative language in the FY 2017 Consolidated Appropriations Act directing NASA to launch a lander mission by 2024. What was NASA's rationale for not requesting funding for a Europa lander in this budget?
    a. If NASA doesn't believe that 2024 is the optimal timeframe for a lander mission to Europa, what is NASA's preferred time table for such a mission and why?

        Answer: NASA's Planetary Science portfolio currently supports two large strategic missions in the five-year budget horizon (Mars 2020 and Europa Clipper); thus, the Europa Lander mission was not included in the FY 2018 President's budget request since it could not be accommodated without significant impacts to other programs. Additionally, a Europa lander was not in the last planetary Decadal Survey conducted by the National Academies.

Beginning design and development work on a lander before the science community is able to evaluate data from the Europa Clipper mission may impact the science return from a future lander mission.

5. NASA expects there to be several missions operating on Mars in the early 2020s. The Mars Reconnaissance Orbiter, which provides the vast majority of the data relay between surface vehicles and Earth, will have been operating for 15 years by then.
    a. How does NASA plan to meet the increasing Mars-Earth telecommunications needs?

    Answer: NASA's Deep Space Network (DSN), which has been in operation for over 50 years, provides communication and tracking services to about 35 NASA and non-NASA missions beyond geosynchronous orbit (26,000 miles above the Earth's surface). Its three deep space communication complexes, all of which are owned by NASA, are located in Goldstone, California; Canberra, Australia; and Madrid, Spain. The sites are separated by approximately 120 degrees of longitude to ensure that any spacecraft in deep space can communicate with at least one station at all times as the Earth rotates. The Space Communications and Navigation (SCaN) Program actively seeks to implement operational efficiencies to help fund modernization and upgrade activities.

    Realizing the need for additional capacity in the early 2020s, SCaN has been actively working to modernize and upgrade the DSN capabilities in addition to securing cross support agreements with other space agencies. SCaN established the DSN Aperture Enhancement Project (DAEP) to modernize and upgrade the DSN's ground stations, and to enhance capacity, improve flexibility to support customer missions, and reduce operations and maintenance costs. To date, SCaN has added two new 34-meter antennas at the Canberra, Australia facility and is actively working to build and bring online two additional antennas in Madrid, Spain. The new 34-meter antennas are easier and more cost-effective to maintain, in addition to providing the same or better performance as the 70-meter antennas when arrayed. In addition to cross-support agreements completed or in work with other space agencies, SCaN is working with the Italian Space Agency to use their Sardinia 64-meter antenna as a backup capability. Moreover, SCaN is presently working on adding capabilities to the existing antennas to support up to four users' co-located missions per antenna. SCaN is maintaining an effective operation and maintenance effort, leveraging efficiency to increase productivity and reliability.

    SCaN is working closely with the Science Mission Directorate's Mars Program to address future requirements, and is conducting studies to identify future space-based relay communication and navigation architectures for Earth and Mars that are infused with technologies under development to support NASA missions in the 2022 and beyond timeframe. Evolving space communication systems will transform future NASA mission capabilities. SCaN's technology development

effort invests in leading-edge communications technologies, and enables, improves, and matures available spacecraft communication and navigation technologies to build capabilities for both ground and space-based use. Some of the technologies that SCaN is currently working on are optical communication and software-defined radios.

b. What is the confidence level that NASA's current plans will avoid a gap in telecommunications between Mars and Earth? What would the consequences of a telecommunications gap be?

Answer: As noted in the response to Question #5a, SCaN is actively working to modernize and upgrade the DSN and we do not anticipate a gap in telecommunications between Mars and Earth. The DAEP modernizes and upgrades the DSN's ground stations to enhance capacity, improve flexibility to support customer missions, and reduce operations and maintenance costs. Without continuing maintenance and repair work, the Agency would be at risk of losing valuable data as the existing antennas required significant repair work.

6. NASA, in its FY 2018 request, proposes to try to leverage NASA and DOD initiatives in hypersonics. Please provide details on how NASA will apply its expertise in hypersonics and unique test facilities to complement DOD's efforts. In what areas, if any, will civil aviation benefit from such research?

Answer: NASA is focused on developing the next generation of hypersonic capabilities. These capabilities have the potential to support both military and civil applications in the future. By coordinating closely with the DoD, NASA can leverage extensive DoD ground and flight test opportunities to provide data and insight that helps support NASA research. For example, experimental data can be compared to the results of computer simulations, which helps validate NASA's computational capabilities. At the same time, by working closely with the DoD, NASA is able to provide technical support and complementary research that enhances the DoD projects and also reduces technical risk. Therefore, NASA can focus on generating tools and technologies for the next generation of hypersonic applications while having a direct benefit to current DoD efforts.

NASA has worked with the DoD to identify the suite of test facilities that are most critical for developing new hypersonic capabilities. A number of these facilities are owned and operated by NASA, and some are used by the DoD to generate ground test data. In addition, NASA coordinates with the DoD to ensure that accompanying test technologies and knowledge about conducting hypersonic testing are shared. NASA is also cooperating with the DoD in more foundational research and developing the next generation technical workforce. In particular, NASA is well-coordinated with the Air Force Office of Scientific Research and supports research with the university community.

While the first applications of hypersonic technologies will be for military missions, there is a potential for future civil applications. Access to space is one such civil mission that may be enhanced through air-breathing hypersonics. Some companies are also exploring hypersonic civil transports such as Boeing's recent announcement that it is considering hypersonic civil transport as a future technology. Research on specific hypersonic tools and technologies can also be leveraged for other aircraft applications. An example is the development of high temperature materials for turbine engine components that was enabled by the NASA research on high temperature materials for hypersonic applications.

7. The in-space robotic servicing initiative known as Restore-L was appropriated $130M in the FY 2017. The FY 2018 budget request would terminate that mission and, according to the accompanying budget justification, "*will transition the Restore-L project to reduce its cost and support a nascent commercial satellite servicing industry", further adding that "NASA is pursuing a potential collaboration with the Defense Advanced Research Projects Agency (DARPA) and with industry to most effectively advance satellite servicing technologies and ensure broad commercial application.*"

   a. Can you talk about the similarities and differences of both activities?

      Answer: The comparison of NASA's Restore-L project to DARPA's RSGS project are provided in the attached table: (SEE ATTACHED TABLE).

   b. In light of the direction in the FY 2017 appropriations, will satellite servicing development activities currently conducted by NASA continue in FY 2017 at the level appropriated or is NASA planning to reduce the scope of its activities in consonance with its proposed termination of Restore-L?

      Answer: For FY 2017, NASA is continuing technology development for the Restore-L satellite servicing project as directed in the Consolidated Appropriations Act of 2017.

   c. What is the status of NASA's discussions with DARPA on a collaborative effort?

      Answer: NASA and DARPA have agreed to a set of goals and principles for a DARPA/NASA collaboration on Satellite Servicing. These include meeting both organizations' goals for advancing satellite servicing capabilities and technologies and transferring those to industry to enable commercial services; accelerating the mission timeline, reducing risk, or increasing the probability of success via resource utilization of all organizations involved; conducting a demonstration in the appropriate orbit that best accomplishes the goals of both organizations; and assuring that technologies and capabilities are transferred broadly to U.S. organizations to support commercial activities. Discussions have been occurring

at the project level between both organizations to identify options for collaboration.

d. How will NASA "*effectively advance satellite servicing technologies and ensure broad commercial application*"?

Answer: NASA's In-space Robotic Servicing/Restore-L project has developed an extensive, written technology transfer plan of which its guiding principles are to provide a level playing field, to share data and information during the various stages of the project, and to foster a constant, iterative dialogue along the way. In August 2016, NASA issued a public synopsis of its Restore-L plan which provided background on the project, introduced the objectives of testing crosscutting satellite servicing technologies, stated the plan to transfer technologies to U.S. commercial entities to help jump start a commercial on-orbit robotic satellite servicing capability, and solicited interest and feedback on this plan. In April 2017, NASA held its first in a series of day long industry workshops on In-Space Robotic Servicing/Restore-L to present information on technology development to date and will continue periodically conducting these workshops through 2019. Ongoing activities include responding to inquiries, continued dialogue as requested, and controlled access to facilities to help industry obtain the information they need to advance their business plans for a commercial satellite servicing industry.

8. The FY 2018 budget makes clear that leveraging public-private partnerships is a priority for NASA, but offers few details on how these partnerships will be used. Can you provide specifics on any new public-private partnerships being planned for FY 2018? Will there be any changes to the way NASA conducts its partnerships?

Answer: NASA regularly partners with U.S. industry and other private sector partners. Such partnerships are instrumental in supporting the Agency's strategic plan and Agency objectives, including expanding human knowledge; advancing U.S. competitiveness; disseminating the results of NASA's activities to educate and inspire; and facilitating the efficient use and management of Agency infrastructure and capabilities. Currently, NASA has about 1,200 active partnerships with U.S. industry and other private sector entities. By supporting the development and utilization of new knowledge and technologies by its domestic partners, NASA helps improve America's industrial supply chain, maximizes the U.S. taxpayers' return from their investment in NASA research and development, and leverages private sector approaches to develop and commercialize technology.

NASA employs several kinds of commercial partnership mechanisms to address U.S. space capabilities, including – but not limited to – Federal Acquisition Regulation (FAR)-based contracts to fulfill Agency requirements, as well as funded and unfunded Space Act Agreements (SAAs), which support and encourage commercial innovation. The

Commercial Resupply Service (CRS) contracts, under which Space Exploration Technologies (SpaceX) and Orbital ATK have been providing cargo resupply to the International Space Station (ISS), are examples of the former. NASA's Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) initiative, which has established multiple no-funds-exchanged SAA partnerships with U.S. private sector entities, is an example of the latter.

NASA will continue to actively engage U.S. private sector partners in FY 2018 and beyond. Some examples of planned partnerships include the following:

A nonreimbursable (no exchange of funds) collaboration with a U.S. university to develop and test water and solid waste treatment technologies.

A reimbursable arrangement (wherein the partner reimburses NASA for its costs) with a consortium of U.S. companies to develop infrared (IR) technology and to advance the general state of the art in infrared detectors to enable commercial production of such detectors for supply to U.S. government and commercial customers.

A reimbursable arrangement with a U.S. company to provide support and advice for commercializing space-based optical communications technology and improve upon the speed of the optical data communication.

A reimbursable arrangement with a U.S company to provide an objective, non-industry assessment of a unique, but broad, class of printed wiring boards produced in the supply chain for the purpose of developing a risk based protocol to insure the integrity and flightworthiness of industry printed wired boards (PWBs).

A reimbursable arrangement with a U.S. university to provide NASA optical communications expertise to assist testing and modeling of atmospheric effects on laser propagation at several elevations.

A nonreimbursable collaboration with a U.S. university to facilitate development of nano-satellite sub-systems and sensors.

NASA has been very effective in its utilization of partnerships with private sector partners and does not currently anticipate significant changes in the way the Agency conducts its partnerships function; however the Agency is continuously seeking to enhance its effectiveness in engaging U.S. private sector partners for mutual benefit.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"An Overview of the National Aeronautics and Space Administration Budget for Fiscal Year 2018"

Mr. Robert M. Lightfoot, Jr., Acting Administrator, National Aeronautics and Space Administration (NASA)

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

1. NASA has a unique and important role when it comes to inspiring our nation's next generation of scientists and engineers. That is why I am very troubled that the President's FY 2018 budget request proposes to eliminate NASA's Office of Education.
    a. What is the justification for this decision?

    Answer: The Office of Education has experienced significant challenges in implementing a focused NASA-wide education strategy. Additionally, the Office of Education lacks sufficient outcome measures to assess the effectiveness of its programs. During this time of fiscal constraint, the federal government is eliminating programs that have not demonstrated effectiveness. NASA's mission content will continue to inspire the next generation through the many ways that our work excites and encourages discovery by learners and educators.

    b. What is the rationale for eliminating the Office rather than addressing any management issues that have been identified?

    Answer: The agency is addressing these and other concerns at this time. An agency-wide approach to Education and Outreach is in work as part of NASA's Education & Outreach Business Services Assessment (BSA). Although this assessment began prior to the Administration's proposal to eliminate the Office of Education, the results of this process enables the agency to increase efficiency and optimize the synergies between STEM engagement and outreach activities that expose our Nation's learners to NASA's unique missions.

    c. How does the potential elimination of the Office impact on NASA's role of fostering the recruitment and retention of our Nation's next generation of scientists and engineers?

    Answer: NASA will continue to inspire the next generation through its missions and the many ways that our work excites and encourages discovery by learners and educators. Internships, fellowships, and outreach activities funded outside the Office of Education are planned to continue. While the percentage may vary from year to

year, on average nearly 70 percent of internships at NASA field centers are funded outside of the Office of Education, and will continue even without a traditional Office of Education. The Science Mission Directorate (SMD) STEM Science Activation program will continue to focus on delivering SMD content to learners of all ages through cooperative agreement awards.

2. The budget proposal does not include funding for Space Grant, EPSCoR, or MUREP, contrary to longstanding Congressional support for these programs. What is the specific justification for eliminating these programs?

   Answer: While NASA has long tracked output data (e.g., number of people funded, number of papers generated, number of events supported) for these projects, outcome-related data demonstrating program effectiveness has been insufficient to fully assess their impact. NASA believes that STEM engagement efforts, currently undertaken by mission directorates and other functional offices, will provide opportunities for learners to participate in STEM engagement activities that capitalize on NASA-unique assets and content.

3. I understand that the Wide Field Infrared Survey Telescope (WFIRST) is nearing its System Requirements Review. I am encouraged to hear that NASA is taking feedback from the National Academies to heart and will be conducting an independent technical, management, and cost review of the mission prior to the System Requirements Review and the start of development. What other lessons NASA has learned from JWST and how you will apply those lessons to the development of WFIRST and future large scale missions?

   Answer: The root causes of the James Webb Space Telescope overrun were an initial budget estimate that was too low; growth in capabilities and complexity; and reserves that were skewed to the outyears providing inadequate resources in the early years when technical challenges arose. To ensure an accurate budget estimate, the WFIRST team has acquired seven independent cost estimates over the past six years which validated NASA's estimates for cost, schedule, and risk each time. Now that the project is in formulation, NASA has initiated an independent, external review over the next several months on the scope of the WFIRST project to help ensure it would provide compelling scientific capability with an appropriate, affordable cost and a reliable schedule. NASA intends to incorporate these recommendations into its design and plans for WFIRST before proceeding with development of the mission. A similar independent review was conducted during the development of Webb, but much later in the development cycle. To provide management insight into the project's performance against commitments, we are utilizing earned value management tools, tracking technical, schedule, and cost metrics during each monthly review. Finally, the WFIRST design incorporates only two new technologies, both of which have completed laboratory demonstrations one full year prior to the date required by NASA standards; one of the new technologies, the coronagraph instrument, is classified as a

"technology demonstration," i.e., its performance does not affect our overall mission success criteria. This reduces the technical risk of the WFIRST mission compared to Webb.

4. Most experts agree that the most significant factor preventing the achievement of the full potential of unmanned aircraft systems is the need to ensure that all vehicles flying in the National Airspace System (NAS) can do so safely.
    a. What is the status of NASA's collaborative efforts with FAA to safely integrate UAS into the NAS?

    Answer: NASA is working closely with the FAA to understand barriers to integration of UAS into the National Air Space (NAS), to prioritize and address those barriers where NASA has unique expertise and to effectively transition research findings to appropriate offices in the FAA. NASA has provided research results from simulations and flight test that have been used to define Minimum Operational Performance Standards for Command and Control and Detect and Avoid functions for an unmanned aircraft transiting Class E and G airspace, in route to operations in Class A airspace. NASA is currently planning research activities to provide similar research findings for a mission that includes sustained operations in Class E Airspace. This is a significantly more challenging mission for UAS.

    NASA also is collaborating with the FAA to explore the technical challenges that must be addressed to safely enable operations of small UAS at low altitudes through the UAS Traffic Management (UTM) project. UTM is a research platform that is intended to enable safe airspace operations for all operators by providing common picture of the airspace, allows for exchange of information among aircraft and operators as well as with FAA's Air Traffic Management systems. NASA is working closely with FAA, other federal agencies and industry to develop and validate airspace operations, functions, roles and responsibilities, and integration requirements associated with UTM.

    NASA participates in multiple FAA-organized forums to solicit the unfiltered "voice" of industry on UAS issues, with NASA experts currently serving on the ID and Tracking Aviation Rulemaking Committee as well as the FAA's Drone Advisory Committee. NASA is active in discussion of UAS integration policy issues through the U.S. Government UAS Executive Committee and its attendant Senior Steering Group. In addition, NASA is working closely with the FAA chartered test sites and using their unique capabilities to augment NASA research capabilities.

    FAA and NASA have formed two UAS-related Research Transition Teams (RTT) to ensure that NASA research outcomes provide valuable information to the FAA for their decision making related to UAS operations. FAA provides subject matter expertise to NASA through the RTTs to ensure high relevancy of NASA's research. One RTT is focused on UTM concepts and requirements for data exchange and information architecture, communication and navigation and detect/sense and avoid. Through the RTT, NASA and FAA are developing a comprehensive concept of operations starting from NASA's original UTM concept, data exchanges among

airspace users, information architecture, sense and avoid, and performance technologies. The UTM RTT will culminate into key technical transfers of concepts and technologies to FAA, as well as a joint UTM pilot program plan.

A second FAA-NASA RTT is focused on issues associated with integrating larger (greater than 55 lbs), higher performance UAS into the NAS. Working Groups have been established to address Detect and Avoid, Command and Control, Operations and Advanced Concepts and a No Chase Certificate of Authorization (COA).

All of these efforts have resulted in increased efficacy of NASA's research related to UAS integration and effective use of resources to address policy and rulemaking associated with routine UAS integration into the Nation Airspace System.

b. What impact would privatizing FAA's air traffic control system have on such collaborative efforts?

Answer: NASA does not anticipate that privatizing the FAA's air traffic control function would have a substantial impact on our collaboration with the FAA as it relates to UAS integration. NASA will continue to research concepts and technologies related to safe integration of UAS into the national air space, and transition them to the appropriate entities in the FAA and/or a newly privatized operational organization. NASA has extensive experience working with and transitioning technologies to government and private sector civil aviation organizations and companies. NASA has used active air traffic controllers in our research in the past and we would anticipate still having access to the cadre of active air traffic controllers to increase the validity of our research findings.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"An Overview of the National Aeronautics and Space Administration Budget for Fiscal Year 2018"

Mr. Robert M. Lightfoot, Jr., Acting Administrator, National Aeronautics and Space Administration (NASA)

Question submitted by Rep. Zoe Lofgren, House Committee on Science, Space, and Technology

1. As you know, I'm fortunate enough to have a NASA Center, NASA Ames, near my district in California, and many of my constituents who live in San Jose work there. The research being done at NASA Ames fits well in to the Silicon Valley personality- it's innovative and cutting edge.

   One of those programs is the Stratospheric Observatory for Infrared Astronomy (SOFIA), the world's largest airborne observatory. The aircraft is based at the Armstrong Flight Research Center in Palmdale and the science and mission operations are based at NASA Ames.

   The airplane-based telescope has supported astronomical research that cannot be done in other ways, providing a unique vantage on our solar system, galaxy and the history of the Universe. SOFIA was built and planned to be operated as a partnership with the German Space Agency. It also provides a unique educational platform, including K-12 science teachers on research flights, with the professional astronomers and technicians.

   Yet, the funding for SOFIA ramp down after the senior review in 2019. This seems to set up a contentious situation where SOFIA will have to take funding from other programs.

   a. If SOFIA has a successful senior review, from where will the money be restored?

      Answer: A funding line for a SOFIA extended mission is held under "Cosmic Origins Future Missions," however, the outyear budgets are notional. SOFIA's budget will be determined as part of the FY 2020 initial operating plan following the 2019 Senior Review.

   b. Is ramp down in funding two years before a planned senior review consistent with how other projects of similar size have been treated?

      Answer: With the reduction in jet fuel prices over the past years, and SOFIA's increasing efficiencies in operations, SOFIA has accumulated uncosted carry over. In other words, they are spending less than their appropriated budget. By reducing the SOFIA budget slightly in FY 2018 and FY 2019, it is expected that the SOFIA project will burn down the uncosted carryover with no impact to science or operations.

NASA is continuing to maintain and update SOFIA's capabilities so that SOFIA is capable of operating should the Senior Review conclude that it continues to be scientifically productive relative to its cost. NASA and our German partners are developing a suite of state-of-the-art instruments that provide an order-of-magnitude more science capability than the original suite of instruments that was selected 20 years ago. For example, NASA has developed the High-Resolution Airborne Wideband Camera-plus (HAWC+), which recently began operations on SOFIA. Our German partners have developed the Upgraded German Receiver for Astronomy at Terahertz Frequencies (upGREAT), which is currently available to SOFIA users. NASA has begun development of the High-Resolution Mid-Infrared Spectrometer (HIRMES), which will begin operations on SOFIA in 2019, and we will be soliciting proposals in 2018 for a fourth-generation instrument to be developed for use on SOFIA after that. The recently built fuel farm at the Armstrong Aircraft Operations Facility provides the necessary infrastructure to safely support SOFIA refueling. We continue to acquire and steward the spare aircraft parts and experienced personnel necessary to maintain SOFIA's operational capability.

Material requested for the record on page 77, line 1826, by Representative Rohrabacher during the June 8, 2017, hearing at which Administrator Robert Lightfoot testified.

NASA is focused on completing Space Launch System (SLS) development, producing the first SLS flight articles, and ensuring a sustained cadence of exploration missions that will ensure continued U.S. leadership in deep space exploration through the 2020s and beyond. Although it is premature to provide a detailed cost for an SLS launch at this stage in the program's life cycle, NASA's preliminary estimate for the marginal cost of an SLS launch early in the program's production and operations phase, is on the order of $0.7 - 1.0 billion, which represents the cost of a second SLS in a given year where the fixed costs are covered by the first SLS launch. This preliminary estimate of the marginal cost includes the SLS core stage, boosters, and Exploration Upper Stage, but does not include Orion and/or cargo elements, or enterprise/ground operations and integration costs. NASA has assessed the results from a recent affordability Request for Information (RFI) and will work with industry to reduce overall costs once SLS and ground systems enter the production and operations phase.

Material requested for the record on page 78, line 1847 and 1854, by Representative Rohrabacher during the June 8, 2017, hearing at which Administrator Robert Lightfoot testified.

Orbital debris mitigation remains an important effort internationally given the ever increasing number of countries and other entities developing space capabilities. The U.S. continues to adhere to and seek international implementation of space debris mitigation measures through national policies, laws, and regulations, as well as research into new capabilities for better characterization of the space debris populations and new technologies that might ultimately remove space debris from orbit. More specifically, in United Nations meetings and other international fora, the United States continues to encourage international adherence to the Inter-Agency Space Debris Coordination Committee (IADC) Space Debris Mitigation Guidelines and the guidelines developed by the Committee on the Peaceful Uses of Outer Space (COPUOS) of the United Nations, which were endorsed by United Nations General Assembly in 2007, as vital in the effort to control the space debris problem for the safety of future space missions. In addition, NASA is participating in a new activity to improve the IADC Space Debris Mitigation Guidelines. This effort aims to quantify several elements in the guidelines, including the 25-year post mission decay rule for LEO spacecraft and upper stages, the 1 in 10,000 random reentry human casualty risk threshold, the 0.001 probability limit for accidental explosions during mission operations, and the 0.9 reliability threshold for post-mission disposal operations. The activity is expected to be completed with updates to the IADC Space Debris Mitigation Guidelines in 2018.

While it is under study, active removal of orbital debris removal has far reaching technical, legal, and economic implications. The remediation of the near-Earth space environment will necessarily involve an international effort. Since international treaties prevent a country from removing space objects that do not belong to it, the United States, by itself, cannot solve the orbital debris problem. NASA works with our international partners through the Inter-Agency Space Debris Coordination Committee (IADC) and the Committee on Peaceful Uses of the Outer Space of the United Nations (UN COPUOS). The IADC has an on-going study to quantify the benefits of active debris removal but the study will not be concluded before 2019. The UN COPUOS is developing a set of guidelines for the Long-Term Sustainability of Outer Space Activities (LTS).

There have been some international meetings focusing on active debris removal in recent years, but they have focused on concept and technology development rather than international coordination for ADR operations. Example of such meetings include the following:

- NASA and DARPA co-organized the first-of-its-kind "International Conference on Orbital Debris Removal" in Chantilly, VA, in 2009. The conference was well attended by approximately 280 participants from 9 foreign countries and the United States. More than 50 presentations were grouped into 10 sessions ranging from defining the problems, to small and large debris removal, and to the legal and economic issues for removal operations.

• The French Space Agency, CNES, has organized a bi-annual "European Workshop on Active Debris Removal" since 2010. It was renamed "European Workshop on Space Debris Modeling and Remediation" in 2014. The event regularly attracts about 150 technical experts for presentations on various technology development, testing, and feasibility studies. NASA provided keynotes at several workshops.

The orbital debris problem is creating a major challenge for space situational awareness (SSA) and for the safe operation of U.S. space assets. NASA is taking a number of steps to address this challenge, and will continue to work to better define the orbital debris population for near-term debris impact risk assessments, protect critical space assets, evaluate the far-term sustainability of the environment, and initiate early technology development to reduce the risk in the future.

Appendix II

Additional Material for the Record

STATEMENT SUBMITTED BY FULL COMMITTEE
RANKING MEMBER EDDIE BERNICE JOHNSON

OPENING STATEMENT

Ranking Member Eddie Bernice Johnson (D-TX)

House Committee on Science, Space, and Technology
Subcommittee on Oversight
Subcommittee on Research & Technology
"Bolstering the Government's Cybersecurity: Lessons Learned from WannaCry,"
June 15, 2017

Thank you Chairman LaHood and Chairwoman Comstock.

As I have said many times on this subject before, cybersecurity is a difficult threat to confront. It is continually evolving and constantly presenting serious dangers to our personal and national security. Every time you pick up a newspaper, it is apparent that no one is safe from these threats. Cybersecurity weapons can compromise our government systems, financial systems, healthcare services, electric power grid, sensitive private information, and even our voting systems – the very lifeblood of our democracy.

Although some cybersecurity threats are highly sophisticated, backed by well-trained foreign actors and nation states, even crudely developed cyber threats can be successful because they rely on the flaws and vulnerabilities of unsuspecting human beings to help launch penetrations of digital networks.

Personal, private sector, and federal government vigilance is key to confronting this threat. A 22-year-old cybersecurity analyst employed by Kryptos Logic helped derail the recent Ransomware attack resulting from the WannaCry virus because he acted quickly. That is one lesson learned from the WannaCry attack. Another lesson is the importance of quickly implementing security patches issued by software providers. U.S. government and private sector systems were largely immune to WannaCry because our systems managers did just that.

Like many other cyber threats, the success of WannaCry was dependent on individuals inadvertently helping it infect computers and proliferate. Those who are simply users of digital technology today, which includes all of us, our children and grandchildren alike, should all heed these lessons. Empowering individuals to take appropriate precautions against the wide-range of current and emerging cyber threats and encouraging them to remain vigilant in both the work place and at home is one of our best defenses. People are critical to ensuring our cyber-security. The best technical tools in the world won't do much good when individuals mistakenly open the door to these digital dangers.

I look forward to the testimony of our witnesses. I would also like to thank retired Brigadier General Gregory Touhill for being here today. He has had a long career in cybersecurity. He was a deputy assistant secretary for cybersecurity and communications at DHS and was appointed as the first federal Computer Information Security Officer (CISO) last September, a position he left in January of this year. Gen. Touhill is currently an Adjunct Professor of Cybersecurity & Risk Management at Carnegie Mellon University.

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

House Committee on Science, Space, and Technology
Subcommittee on Space
"An Overview of the National Aeronautics and Space Administration Budget for Fiscal Year 2018"
June 8, 2017

Good morning.

I join the Chairman in welcoming you, Mr. Lightfoot. We look forward to your testimony. NASA is fortunate that an individual as experienced as you is serving as Acting Administrator.

This is the first budget proposal of the Trump Administration, and relative to the ill-considered funding cuts to science in other Federal R&D agencies, the request of about 19.1 billion dollars for NASA can be considered good news.

That said, what concerns me is that the priorities represented in this Fiscal Year 2018 budget proposal for NASA appear to weaken the efforts Congress has taken to put NASA on a strong and stable footing. In particular, it would cut over a half billion dollars from the funding that Congress appropriated for NASA in the Fiscal Year 2017 Consolidated Appropriations Act. And it would shrink NASA's purchasing power significantly over the five-year budget horizon at a time when NASA is striving to meet several major milestones in the 2018 timeframe, including

- The launch of the James Webb Space Telescope;
- The certification of two U.S. space transportation systems for carrying crew to the International Space Station; and
- The first test flight of the integrated Space Launch System and the Orion crew vehicle.

Cuts to NASA's budget will not make the challenges of meeting these milestones any easier.

But what really puzzles and upsets me is why an agency whose mission is to inspire would attempt to eliminate the Office of Education, and for no good reason? Foundational NASA education programs such as Space Grant, EPSCoR, and MUREP are simply terminated in this budget request. That is a sad indicator of the priorities represented in this Fiscal Year 2018 budget proposal.

The same can be said for the proposal to cut five Earth science missions and to reduce funding for future Earth science research grants. We need more data and research to understand and address changes to our Earth system, and in particular, our climate, not less.

Mr. Chairman, while I appreciate that the top-line budget proposal for NASA is a good start, it is clear that we on this Committee and in this body, have work to do to ensure that we continue to set NASA on the strong and stable path that the Congress established with the Fiscal Year 2017 appropriations and the NASA Transition Authorization Act.

I never tire of reiterating that NASA is a crown jewel of America's research and development enterprise. It advances knowledge, promotes technological innovation, projects a positive image of America throughout the world, and inspires. Its workforce is dedicated and accomplished. NASA deserves our support.

I look forward to working the Administration, with you, Mr. Chairman, and with this Committee to do just that.

Thank you and I yield back.

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