AMERICA'S HUMAN PRESENCE IN LOW-EARTH ORBIT

HEARING

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

ONE HUNDRED FIFTEENTH CONGRESS

SECOND SESSION

MAY 17, 2018

Serial No. 115–60

Printed for the use of the Committee on Science, Space, and Technology

Available via the World Wide Web: http://science.house.gov

U.S. GOVERNMENT PUBLISHING OFFICE
30–323PDF WASHINGTON : 2018

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HON. LAMAR S. SMITH, Texas, *Chair*

FRANK D. LUCAS, Oklahoma
DANA ROHRABACHER, California
MO BROOKS, Alabama
RANDY HULTGREN, Illinois
BILL POSEY, Florida
THOMAS MASSIE, Kentucky
RANDY K. WEBER, Texas
STEPHEN KNIGHT, California
BRIAN BABIN, Texas
BARBARA COMSTOCK, Virginia
BARRY LOUDERMILK, Georgia
RALPH LEE ABRAHAM, Louisiana
GARY PALMER, Alabama
DANIEL WEBSTER, Florida
ANDY BIGGS, Arizona
ROGER W. MARSHALL, Kansas
NEAL P. DUNN, Florida
CLAY HIGGINS, Louisiana
RALPH NORMAN, South Carolina
DEBBIE LESKO, Arizona

EDDIE BERNICE JOHNSON, Texas
ZOE LOFGREN, California
DANIEL LIPINSKI, Illinois
SUZANNE BONAMICI, Oregon
AMI BERA, California
ELIZABETH H. ESTY, Connecticut
MARC A. VEASEY, Texas
DONALD S. BEYER, JR., Virginia
JACKY ROSEN, Nevada
CONOR LAMB, Pennsylvania
JERRY MCNERNEY, California
ED PERLMUTTER, Colorado
PAUL TONKO, New York
BILL FOSTER, Illinois
MARK TAKANO, California
COLLEEN HANABUSA, Hawaii
CHARLIE CRIST, Florida

CONTENTS

May 17, 2018

AMERICA'S HUMAN PRESENCE IN LOW–EARTH ORBIT

THURSDAY, MAY 17, 2018

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

The Committee met, pursuant to call, at 10:03 a.m., in Room 2318, Rayburn House Office Building, Hon. Lamar Smith [Chairman of the Committee] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

Congress of the United States
House of Representatives

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
2321 RAYBURN HOUSE OFFICE BUILDING
WASHINGTON, DC 20515–6301
(202) 225–6371
www.science.house.gov

America's Human Presence in Low-Earth Orbit

Thursday, May 17, 2018
10:00 a.m.
2318 Rayburn House Office Building

Witnesses

Mr. William Gerstenmaier, Associate Administrator, Human Exploration and Operations Directorate, NASA

Dr. Bhavya Lal, Research Staff, Science and Technology Policy Institute

Dr. Elizabeth R. Cantwell, CEO, Arizona State University Research Enterprise (ASURE); Professor of Practice, School for Engineering of Matter, Transport & Energy, Arizona State University

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: May 17th, 2018
SUBJECT: Full Committee Hearing: "America's Human Presence in Low-Earth Orbit"

On Thursday, May 17 at 10:00 a.m. in Room 2318 of the Rayburn House Office Building, the Committee on Science, Space, and Technology will hold a hearing titled, "America's Human Presence in Low-Earth Orbit."

Hearing Purpose

The United States is committed to continuing its presence on and support for the International Space Station (ISS) to 2024. However, the Administration has stated its intention that direct Federal support for the ISS should end in 2025. This hearing will explore that choice, how we can determine the best policy outcome, and other essential questions about human spaceflight advanced by this discussion.

Witnesses

- **Mr. William Gerstenmaier**, Associate Administrator, Human Exploration and Operations Directorate, NASA
- **Dr. Bhavya Lal**, Research Staff, Science and Technology Policy Institute for Defense Analysis
- **Dr. Elizabeth R. Cantwell**, CEO, Arizona State University Research Enterprise (ASURE); Professor of Practice, School for Engineering of Matter, Transport & Energy, Arizona State University.

Staff Contact

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

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

Good morning to you all, and welcome to today's hearing titled, "America's Human Presence in Low-Earth Orbit." I'll recognize myself for an opening statement and then the Ranking Member.

Our nation faces important questions about future space exploration. Will the International Space Station stop receiving federal support in 2025? If so, under what conditions? What is the future of America's human presence in low-Earth orbit? Beyond that, what is the future of human presence on the Moon and Mars?

The International Space Station has been authorized and funded to operate until 2024. Decisions about the long-term future of the ISS impact the future of America's human space exploration program. Unless NASA's budget is significantly increased, there are not enough funds both to maintain direct federal support for the ISS and return American astronauts to the surface of the Moon in the 2020s. And without a sharp increase in funding for NASA, we cannot ensure American leadership in human deep space exploration in the next decade and beyond.

NASA announced an ISS transition plan at the end of March. According to the proposal, the United States should not continue direct federal support for ISS operation beyond 2024. The private sector—commercial space—may well pick up where NASA left off.

In addition to the transition of the ISS, a related but important question is the future of America's human presence in low-Earth orbit. After 2025, should Americans maintain some human presence in low-Earth orbit, even on a limited basis? But, having, quote, "American human presence in low-Earth orbit," does not necessarily mean continuing to operate the ISS. Discussing continued human presence and continued operation of the ISS are related, but distinct subjects.

Existing law can help guide this discussion. The 2017 NASA Transition Authorization Act reaffirms the principle of "continuity of purpose." It also establishes that extending human presence throughout the solar system is a long-term goal for NASA. It directs NASA to follow a steppingstone approach to exploration. This involves expanding human presence from low-Earth orbit to the Moon, from the Moon to Mars, and then from Mars to other bodies throughout the solar system.

The 2018 NASA Authorization Act was approved by the Science Committee on a bipartisan vote, and the act supports the Administration's transition plan in fiscal year 2019. It's my hope that this hearing will help us evaluate the transition of the ISS and continued American presence in low-Earth orbit.

[The prepared statement of Chairman Smith follows:]

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

For Immediate Release
May 17, 2018

Media Contacts: Thea McDonald, Brandon VerVelde
(202) 225-6371

Statement by Chairman Lamar Smith (R-Texas)

America's Human Presence in Low-Earth Orbit

Chairman Smith: Our nation faces important questions about future space exploration. Will the International Space Station (ISS) stop receiving federal support in 2025? If so, under what conditions? What is the future of America's human presence in low-Earth orbit? Beyond that, what is the future of human presence on the Moon and Mars?

The ISS has been authorized and funded to operate until 2024. Decisions about the long-term future of the ISS impact the future of America's human space exploration program.

Unless NASA's budget is significantly increased, there are not enough funds both to maintain direct federal support for the ISS and return American astronauts to the surface of the moon in the 2020s. And without a sharp increase in funding for NASA, we cannot ensure American leadership in human deep space exploration in the next decade and beyond.

NASA announced an ISS transition plan at the end of March. According to the proposal, the United States should not continue direct federal support for ISS operation beyond 2024. The private sector—commercial space—may well pick up where NASA leaves off.

In addition to the transition of the ISS, a related but important question is the future of America's human presence in low-Earth orbit. After 2025, should Americans maintain *some* human presence in low-Earth orbit, even on a limited basis? But, having an "American human presence in low-Earth orbit" does not *necessarily* mean continuing to operate the ISS. Discussing continued human presence and continued operation of the ISS are related, but distinct subjects.

Existing law can help guide this discussion. The 2017 NASA Transition Authorization Act reaffirms the principle of "continuity of purpose." It also establishes that extending human presence throughout the solar system is a long-term goal for NASA. It directs NASA to follow a "stepping stone" approach to exploration.

This involves expanding human presence from low-Earth orbit to the moon, from the moon to Mars, and then from Mars to other bodies throughout the solar system. The 2018 NASA Authorization Act was approved by the Science Committee on a bipartisan vote and the act supports the administration's transition plan in FY 2019.

It is my hope that this hearing will help us evaluate the transition of the ISS and continued American presence in low-Earth orbit.

###

Chairman SMITH. That concludes my statement, and the gentlewoman from Texas, the Ranking Member Ms. Johnson, is recognized for hers.

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

Good morning to all, and welcome to our distinguished witnesses. I'm pleased that you're holding this hearing, America's Human Presence in Low-Earth Orbit.

In 1991, the House voted for the first time to reject an attempt to cancel the space station program. More attempts were made to cancel the space program in subsequent years, but each time, it was kept alive. Those votes to continue the space station weren't easy ones given a series of redesigns, cost growth, and other challenges with the program during that development.

I mention this history, Mr. Chairman, because, had Congress not made a commitment to support the space station and later to extend its operations, we could well have missed acquiring essential knowledge about how to live and safely work in the low-Earth orbit and beyond. We also would have missed an opportunity to inspire our young people to excel, something that the International Space Station continues to do in classrooms across the Nation.

I might add that the six school districts in my district have had the opportunity to have visits with astronauts in the space station, and they were all very, very excited. And I believe that out of that experience many of them will think of the future to use a background in STEM education.

Without the International Space Station, would we have a place, a durable, multination, international partnership that has strengthened this nation, its global leadership, and the vision of peaceful cooperation in outer space? Would we have laid the groundwork for developing a commercial resupply service and soon a commercial crew transportation capability that can help enable sustained commercial engagement in low-Earth orbit?

Looking ahead, as we debate the future of the International Space Station, we find ourselves facing a decision of equal importance to the one we faced in 1991. The NASA Transition Authorization Act of 2017 established long-term goal of sending humans to Mars. We know that such a multi-decadal understanding will be challenging and expensive, and achieving it will be even more challenging if we are also continuing to support the estimated $3–3.3 billion annual cost of keeping the International Space Station operating.

At the same time, the space station supports important research and engineering activities, both public and private, and provides a steppingstone for exploration. For that reason, the Transition Act also calls for an International Space Station transition plan to establish an orderly process by which alternative orbital platforms may be considered and potentially brought on as replacements for the International Space Station.

Although we only recently received the plan, the Administration decided in its fiscal year 2019 budget request to propose ending direct federal funding of the International Space Station in 2025. This is a bold proposal and one that raises a lot of questions.

Mr. Chairman, the future of International Space Station is of great consequence to our continued leadership in space exploration and utilization. Decisions—as it is—as to its funding should not be made lightly, not without sufficient information and debate. As members of the Science Committee, we need to roll up our sleeves, ask the right questions, and focus on the core issues needing our attention.

In that regard, I hope this morning's hearing will shed light on, one, the cost of conducting research on the space station versus alternative model platform; whether the commercial market will be ready to support a purely commercial space station in 2025 without direct U.S. Government funding or, if not, what level of government funding would be needed? Three, whether a national laboratory in low-Earth orbit should be continued following the end of the space station operations and for the conditions and resources that would be needed to transition basic and applied biological and physical sciences research to a commercial or nongovernmental platform.

In closing, Mr. Chairman, there's a lot we need to examine as we contemplate the future of the International Space Station. I hope this morning's discussion is just the first of a series of hearings so that committee members will have the chance to ask questions for the other International Space Station stakeholders who are not represented today. We will need that information if we are to move forward with a thoughtful and constructive NASA authorization bill.

Thank you, and I yield back.

[The prepared statement of Ms. Johnson follows:]

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

House Committee on Science, Space, and Technology
"America's Human Presence in Low-Earth Orbit"
May 17, 2018

Good morning, and welcome to our distinguished witnesses. Thank you, Mr. Chairman, for holding this hearing on *"America's Human Presence in Low-Earth Orbit."*

In 1991, the House voted for the first time to reject an attempt to cancel the Space Station program. More attempts were made to cancel the Station program in subsequent years, but each time, it was kept alive. Those votes to continue the Space Station weren't easy ones, given a series of redesigns, cost growth, and other challenges with the program during its development.

I mention this history, Mr. Chairman, because had Congress not made a commitment to support the Space Station and, later, to extend its operations, we could well have missed acquiring essential knowledge about how to live and safely work in low-Earth orbit and beyond. We also would have missed an opportunity to inspire our young people to excel, something the ISS continues to do in classrooms across our nation.

Without the International Space Station, would we have in place a durable, multi-nation, international partnership that has strengthened this nation, its global leadership, and the vision of peaceful cooperation in outer space? Would we have laid the ground work for developing a commercial resupply service, and soon, a commercial crew transportation capability that can help enable sustained commercial engagement in low-Earth orbit?

Looking ahead, as we debate the future of the International Space Station, we find ourselves facing a decision of equal importance to the one we faced in 1991.

The NASA Transition Authorization Act of 2017 established the long-term goal of sending humans to Mars. We know that such a multi-decadal undertaking will be challenging and expensive, and achieving it will be even more challenging if we are also continuing to support the estimated $3-3.5 billion annual cost of keeping the International Space Station operating.

At the same time, the ISS supports important research and engineering activities, both public and private, and provides a stepping stone for exploration. For that reason, the Transition Act also called for an International Space Station Transition Plan to establish an orderly process by which alternative orbital platforms might be considered and potentially brought on as replacements for the ISS.

Although we only recently received the Plan, the Administration decided in its Fiscal Year 2019 budget request to propose ending direct federal funding of the International Space Station in 2025.

That is a bold proposal, and one that raises a lot of questions.

Mr. Chairman, the future of the International Space Station is of great consequence to our continued leadership in space exploration and utilization. Decisions as to its future should not be made lightly, nor without sufficient information and debate. As Members of the Science Committee, we need to roll up our sleeves, ask the right questions, and focus on the core issues needing our attention.

In that regard, I hope this morning's hearing will shed light on:

1. The costs of conducting research on the Space Station versus an alternative module or platform;
2. Whether the commercial market will be ready to support a purely "commercial" space station in 2025 without direct U.S. government funding, and if not, what level of government funding would be needed;
3. Whether a National Laboratory in low- Earth orbit should be continued following the end of Space Station operations; and
4. The conditions and resources that would be needed to transition basic and applied biological and physical sciences research to a commercial or nongovernmental platform.

In closing, Mr. Chairman, there is a lot we need to examine as we contemplate the future of the International Space Station. I hope this morning's discussion is just the first of a series of hearings so that Committee Members will have the chance to ask questions of the other International Space Station stakeholders who are not represented today. We will need that information if we are to move forward with a thoughtful and constructive NASA Authorization bill. Thank you, and I yield back.

Chairman SMITH. Thank you, Ms. Johnson.

And the Chairman of the Space Subcommittee, the gentleman from Texas, Mr. Babin, is recognized.

Mr. BABIN. Thank you, Mr. Chairman.

The International Space Station, or the ISS, is the crown jewel of America's human spaceflight program. As a representative of Johnson Space Center in Houston, I am proud of the leadership role that Johnson has with the ISS and American human space exploration in general. I'm keenly aware of the importance of the International Space Station to the hardworking professionals at JSC. For them, the ISS is more than just a program of record, it is part of their being. This is why I take with the utmost seriousness the questions our Committee must address on the future of the ISS and America's human spaceflight flight program.

The Trump Administration is a very strong advocate for human space exploration, and I support the Administration's renewed focus. I agree in broad terms with the human exploration plans the Administration has outlined. I appreciate the Administration's invitation to discuss and mature plans for our civil space exploration program, including the ISS. However, we, as a Congress, have a responsibility to think through the issues on our own and reach our own conclusions, which is why we are here today.

I believe that doing exploration right means that anywhere we establish a human presence in space, we must fulfill two main objectives. First, we must make that presence sustainable. Second, we must use that presence as a jumping-off point to extend our reach even further. This discussion, along with maintaining continuity of purpose, are key themes in the 2018 NASA Authorization Act recently passed out of this Committee on a bipartisan vote.

Section 202 of the Act on the ISS transition reflects a balance, and provides authority and guidance to the Administration to carry out the initial steps of its ISS transition plans but does so on a limited basis. It explicitly limits authorization to carry out the initial exploratory steps of the Administration's plan to fiscal year 2019. Section 202 of the 2018 NASA Authorization Act is good policy that provides a strong foundation for Congress and the Nation as we take our very next steps with the ISS and America's future human presence in LEO.

Four criteria that we may consider for evaluating success of an ISS transition: First, the United States must preserve its global leadership in space, and this means preserving our international partnerships as we continue forward. Second, our presence in LEO should support our journey to the Moon and beyond. Third, staying in LEO should not preclude further human exploration for economic or other reasons. And fourth, as necessary to meet our national interests, we should maintain a regular American human presence—and whether public or private, whether permanent or periodic—in LEO.

I can tell you that failure is not an option. I can also tell you that there are not a lot of scenarios in which a few billion dollars per year can magically be added to NASA's human spaceflight program. Therefore, we have only one option. We must figure out how to lead and cooperate with our private and international partners to make human presence in LEO sustainable. With commitment, we can successfully transition the ISS while maintaining American leadership in human spaceflight.

In closing, I am proud that America has led and will continue to lead the human exploration of the cosmos. I will do everything in my power as Chairman of the Subcommittee to support NASA and American leadership in human space exploration.

I thank the witnesses for their attendance, and I look forward to your testimony. Thank you, Mr. Chairman, and I yield back.

[The prepared statement of Mr. Babin follows:]

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

For Immediate Release
May 17, 2018

Media Contacts: Thea McDonald, Brandon VerVelde
(202) 225-6371

Statement by Chairman Brian Babin (R-Texas)

America's Human Presence in Low-Earth Orbit

Chairman Babin: The International Space Station (ISS) is the crown jewel of America' human spaceflight program.

As a representative for Johnson Space Center, I am proud of the leadership role Johnson has with the ISS and American human space exploration in general. I am keenly aware of the importance of the ISS to the hard-working professionals of Johnson Space Center. For them, the ISS is more than just a program of record, it is part of their being. This is why I take, with the utmost seriousness, the questions our committee must address on future of the ISS and America's human spaceflight program.

The Trump administration is a strong advocate for human space exploration and I support the administration's renewed focus. I agree, in broad terms, with the human exploration plans the administration has outlined. I appreciate the administration's invitation to discuss and mature plans for our civil space exploration program, including the ISS. However, we, as a Congress, have a responsibility to think through the issues on our own and reach our own conclusions, which is why we are here today.

I believe that doing exploration right means that anywhere we establish a human presence in space we must fulfill two main objectives. First, we must make that presence sustainable. Second, we must use that presence as a jumping off point to extend our reach even further.

This discussion, along with maintaining continuity of purpose, are key themes in the 2018 NASA Authorization Act, recently passed out of this committee on a bipartisan vote. Section 202 of the act, on the ISS transition, reflects a balance. It provides authority and guidance to the administration to carry out the initial steps of its ISS transition plan, but does so on a limited basis. It explicitly limits authorization to carry out the initial exploratory steps of the administration's plan to FY19.

Section 202 of the 2018 NASA Authorization Act is good policy that provides a strong foundation for Congress and the nation as we take our next steps with the ISS and America's future human presence in low-Earth orbit (LEO).

Four criteria that we may consider for evaluating success of an ISS transition:

First, the United States must preserve its global leadership in space and this means preserving our international partnerships as we continue onwards.

Second, our presence in LEO should support our journey to the moon and beyond.

Third, staying in LEO should not preclude further human exploration for economic or other reasons.

Fourth, as necessary to meet our national interests, we should maintain a regular American human presence—and whether public or private, whether permanent or periodic—in LEO.

I can tell you that "failure is not an option." I can also tell you that there are not a lot of scenarios in which a few billion dollars per year can magically be added to NASA's human spaceflight program. Therefore, we have only one option: we must figure out how to lead and cooperate with our private and international partners to make human presence in LEO sustainable. With commitment, we can successfully transition the ISS while maintaining American leadership in human spaceflight.

In closing, I am proud that America has led and will continue to lead the human exploration of the cosmos. I will do everything in my power as chairman of the subcommittee to support NASA and American leadership in human space exploration. I thank the witnesses for their attendance and look forward to their testimony.

###

Chairman SMITH. Thank you, Mr. Babin.

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

Mr. BERA. Thank you, Mr. Chairman, and thank you to the Ranking Member.

You know, obviously this is an incredibly important conversation that we're having in terms of what the transition plan is and I look forward to the testimony of the witnesses.

There's broad consensus and agreement both from the Administration and from Congress that as a stretch mission we're looking at human exploration and travel to Mars, as my colleague from Colorado would say, by 2033. And I think that is a good goal to set because, again, you know, much as we did in the age of the Apollo missions, we didn't know how we were going to go to the Moon, let alone how we were going to come back, but we set a goal. We put resources towards that goal. We worked towards it, and we accomplished it. And now, we're setting a stretch goal to get to Mars again by 2033.

As we set that goal, we don't know exactly how we're going to get there. We don't know exactly how we're going to return. We don't know, as a physician, what the human consequences and physiological consequences of extended time in space is going to be extended exposure to radiation, et cetera. To address these issues, we have to have a lab—again, I'm going to approach this as an academic and as a physician to look at these issues. In addition, we don't know the technologies, et cetera. And again, we have to have some venue by which we can do these experiments and learn those technologies that allow us to go deeper into space.

And in that sense, the ISS, its completion in 2011, has given us a very unique asset by which to experiment not just for our desire to go deeper into space. We've also been able to use the ISS as a unique laboratory to help us improve life on Earth, whether it's biomedical discoveries, whether it's other discoveries, it is a very unique asset. And I think that's why this is incredibly important for us to think about.

Resources are always going to be tight, but how do we—not just if we have a workable asset in 2025. I think it would be unconscionable for us not to continue to say, okay, how do we continue to use this asset? Maybe it is what aspect can the commercial sector pick up? What aspect can the international community pick up? But clearly, there's a role for NASA as well and unique capabilities that only NASA can provide.

And again, I'm glad that we are taking up this conversation at this point in 2018 and we're not having this conversation in 2023. I think it's incredibly important for us to do this.

You know, I'll also just add one other component a company that I had a chance to visit when I was down at NASA, Ames, to talk about why this is important was a company called Made In Space. It is working on the NASA Ames facility looking at 3–D printing. I'm a pretty simple—I'm a doctor, not an engineer, but—so 3–D printing to me is 3–D printing. But what they're actually doing is what is 3–D printing in a low-gravity situation? How does that impact things?

And some of the remarkable stuff that they're doing is they're also if we have a lunar mission and return to the Moon, you know, if they simulate the indigenous materials on the Moon to do 3–D printing to use that to build whatever habitats on the Moon, that's pretty remarkable. What that allows us to do is travel with much lighter payloads if eventually we want to create something on Mars. Again, you can't move all those payloads and move all the material, but if you can go to Mars taking the indigenous materials, use that as your building blocks for whatever you're constructing, those are the technologies that, again, you can try to experiment on Earth, but it would be much better to be able to simulate that and build all of that in space.

So I think the ISS, as someone who wants to figure out how we extend the life of the ISS and make this a workable asset until we have an adequate replacement at some time in the future, is something that Congress ought to support. And again, I look forward to hearing the testimony of the witnesses as we think about this transition plan.

And, again, kudos to the Chairman and Ranking Member for having us engage in this conversation in 2018 and not 2033 or 2023. Thank you. We'll be on Mars in 2033.

[The prepared statement of Mr. Bera follows:]

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

House Committee on Science, Space, and Technology
"America's Human Presence in Low-Earth Orbit"
May 17, 2018

Good morning, and thank you, Mr. Chairman, for holding this hearing on *"America's Human Presence in Low-Earth Orbit."* I'd also like to welcome our witnesses, and I look forward to your testimony.

Since the assembly completion of the ISS in 2011, Station crews have been able to focus on using the ISS to test innovative technologies, and carry out the necessary research to support human exploration beyond low Earth orbit.

Congress twice supported extending ISS operations, the first time until 2020, and then again through 2024. Those extensions have helped demonstrate the benefits of the ISS for science and commercial opportunities, including enabling research that may one day improve, prolong, and even save the lives of people here on Earth. As a medical doctor, that is an exciting prospect.

Indeed, the ISS is performing research on how microgravity causes changes in organisms ranging from viruses and bacteria to humans, including altered gene expression and DNA regulation, and changes in cellular function and physiology. Spaceflight-induced health conditions may serve as a model for understanding the impact of conditions here on Earth, such as aging, osteoporosis, and wound healing.

We may be closer to making important discoveries sooner than you think. For example, researchers working for the Department of Defense are using the ISS to investigate the effect of microgravity on wound healing. DOD's investigation is directed at injury repair and how microgravity alters new blood vessel development, which is a key component of wound and tissue repair. I need not tell you that if successful, this would be a game-changer.

That is why I am passionate about ensuring that future microgravity research in space be sustained and that a transition from the ISS to alternative platforms, whenever it may occur, be accomplished smoothly and cost-effectively.

Last year, the Space Subcommittee held a hearing on the ISS. We started to discuss whether or not to extend the ISS beyond 2024, and what role NASA should have in low Earth orbit once ISS operations cease. Today, we will focus on the ISS Transition Plan, which Congress asked for in the 2017 NASA Transition Authorization Act and NASA delivered in late March 2018, almost 4 months late. I hope that our witnesses will engage the Committee in a robust discussion of the critical indicators we might use to gauge the readiness of the commercial market to support a private orbital platform by 2025.

In addition, I look forward to hearing about the essential ISS R&D needed to enable deep space human space exploration and basic research, as prioritized by the decadal survey research. And, let us not forget, Mr. Chairman, that a critical question regarding the future of the ISS and what follows is how the highly-successful International Partnership established under the ISS might continue.

It is clear that decisions we make on how we will operate in low Earth orbit moving forward will have profound consequences.

I look forward to hearing from NASA on its proposed strategy and next steps for moving forward, as well as from the other witnesses on their reactions to NASA's ISS Transition Plan. Thank you, and I yield back.

Chairman SMITH. Thank you, Mr. Bera.

Before I introduce our witnesses today, I'd like to welcome back a former Member of the Committee, and that is the gentleman from Alabama Gary Palmer to my——

[Applause.]

Chairman SMITH. Oh, listen to the enthusiastic response. Gary was a Member of the Committee from 2015 to 2017, took a brief leave of absence, but he's returned to the fold, and so we welcome him back to the Committee.

I might also say—and I'll introduce her at our next hearing, she wasn't able to come today—but Debbie Lesko, the new Member from Arizona is also a member of the Science Committee, and we'll introduce her at the proper time.

But, Representative Palmer, welcome back to the Science Committee.

Our first witness today is Mr. William Gerstenmaier, Associate Administrator of the Human Exploration and Operations Mission Directorate at NASA. He provides strategic direction for all aspects of NASA's human exploration of space and programmatic direction for the continued operation and utilization of the ISS.

Mr. Gerstenmaier began his NASA career in 1977, performing aeronautical research, and has managed NASA's human spaceflight portfolio since 2011. He received a Bachelor of Science in aeronautical engineering from Purdue University, and a Master of Science in mechanical engineering from the University of Toledo.

Our second witness today is Dr. Bhavya Lal, Research Scientist at the Science and Technology Policy Institute at the Institute for Defense Analysis. STPI was established by Congress to support the White House Office of Science and Technology Policy and other executive agencies. At STPI, Dr. Lal leads analysis of space technology strategy and policy for OSTP and the National Space Council, NASA, FAA, and other space-oriented federal agencies and departments.

Dr. Lal holds a Bachelor of Science and a Master of Science in nuclear engineering from MIT, a second Master of Science from MIT's Technology and Policy Program, and a Ph.D. in public policy and public administration from George Washington University.

Our third witness is Dr. Elizabeth R. Cantwell, CEO of the Arizona State University Research Enterprise and Professor of Practice in the School for Engineering of Matter, Transport, and Energy. Dr. Cantwell is responsible for leading the creation, management, and capture of large-scale externally funded programs and projects that advance the university's research enterprise.

Dr. Cantwell earned a Bachelor of Arts in human behavior from the University of Chicago and a Master of Business Administration from the University of Pennsylvania's Wharton School. She also earned her Ph.D. in mechanical engineering from the University of California Berkeley.

We welcome you all, and look forward to your testimony. And, Mr. Gerstenmaier, we'll begin with you.

TESTIMONY OF MR. WILLIAM GERSTENMAIER, ASSOCIATE ADMINISTRATOR, HUMAN EXPLORATION AND OPERATIONS DIRECTORATE, NASA

Mr. GERSTENMAIER. Thank you very much for allowing me to participate in this important hearing on America's human presence in low-Earth orbit.

The ISS has accomplished amazing things and transformed the way that we see human spaceflight. Crews have lived continuously on the ISS for almost 18 years. The ISS has enabled groundbreaking research that has benefited all of us. The ISS has helped NASA prepare for deep space missions. The ISS has allowed us to maintain a leadership role in international spaceflight.

The International Space Station partnership has developed voluntary standards such as the international docking standard that could transform spaceflight for decades to come. These standards will allow anyone to be part of spaceflight by simply designing to these standards. The cooperation of the ISS partners is absolutely amazing and serves as an example of a diverse community working together for common goals.

Lastly, the ISS has enabled innovative U.S. companies to reinvent the launch industry. Further crew private sector development, crew transportation systems, with the aid of NASA, are about ready to go fly. With all these amazing accomplishments from the ISS, it is only fitting that we take time to seriously plan for the transition of ISS in low-Earth orbit.

NASA is preparing to secure the Nation's long-term presence in low-Earth orbit by partnering with industry to develop commercial orbital platforms and capabilities that the private sector and NASA can utilize after the cessation of direct U.S. federal funding for ISS by 2025.

To be clear, NASA is not abandoning low-Earth orbit. We must ensure the right pieces are in place to maintain an operational human presence in low-Earth orbit whether through a modified ISS program, commercial crew—commercial platforms, or some combination of both government and commercial platforms. We are asking industry, academia, and others through a series of funded studies to provide ideas for utilizing the unique properties of space and creating commercial opportunities. We will work with the Space Council and the Department of Commerce to help with the transformation of low-Earth orbit. We have also proposed funds in the 2019 budget to support this transition.

NASA looks forward to working with the Congressional stakeholders, other government agencies, researchers, private industry, and our international partners on the future of ISS in low-Earth orbit to ensure that the United States maintains our human presence—our human leadership in space.

Thank you, and I look forward to your questions.

[The prepared statement of Mr. Gerstenmaier follows:]

HOLD FOR RELEASE
UNTIL PRESENTED
BY WITNESS
May 17, 2018

Statement of

William H. Gerstenmaier
Associate Administrator for Human Exploration and Operations
National Aeronautics and Space Administration

before the

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

Mr. Chairman and Members of the Committee, thank you for the opportunity to appear before you today to discuss the future of the International Space Station (ISS) and NASA's long-term vision for use of low-Earth orbit (LEO).

NASA is preparing to secure the Nation's long-term presence in LEO by partnering with industry to develop commercial orbital platforms, and capabilities that the private sector and NASA can utilize after the cessation of direct U.S. Federal funding for ISS by 2025.

To be clear, NASA is not abandoning LEO. We must ensure the right pieces are in place to maintain an operational human presence in LEO, whether through a modified ISS program, commercial platforms, or some combination of both.

In October of last year, the members of the National Space Council endorsed a recommendation to the President that NASA should return to the Moon. Following that recommendation, on December 11, 2017, the President signed Space Policy Directive 1 which requires NASA to "*Lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities.*" This was nearly 45 years to the moment since the last time that NASA landed humans on the Moon.

NASA will shift the focus of its human exploration program to the Moon and cislunar region with an eye towards Mars, evaluating new habitat technologies, surface transportation systems, landing systems, fuel generation, and storage solutions. In every domain, we intend to renew and strengthen our commitment to American commercial space companies, which are critical partners in the human exploration of the Moon, Mars, and beyond. As NASA reorients the human spaceflight program back to the Moon and beyond to Mars, we will push to develop new ways of operating in LEO that will benefit our exploration endeavors, science goals, and ultimately the taxpayers.

As you know, the ISS currently serves as a unique platform to prepare for human exploration beyond LEO, promotes U.S. economic activity in space, and accelerates innovative research and technology development. Equally important, under the leadership of the United States, the ISS contributes to America's preeminence around the world in space and technological innovation. Since its inception over 30 years ago, the ISS partnership has been a model of peaceful international cooperation. ISS has exceeded all of its original goals and accomplished many things that were never envisioned. Things like helping to establish a cube satellite market and helping to return commercial satellite launches to the U.S. through reduced launch costs. However, NASA must look beyond ISS in its current form in order to continue U.S. leadership in LEO; that is why the NASA Transition Authorization Act of 2017, together with the Administration, are united in transitioning NASA's LEO activities to a model where NASA is one of many customers of a vibrant, U.S.-led, commercial LEO enterprise. The synergy between industry and Government requirements in this endeavor cannot be overstated. We are partners in ensuring American preeminence as the world's leading spacefaring nation.

The Administration views public-private partnerships as the foundation of future U.S. civilian space efforts, and NASA is continuing to develop cooperation on use of the Station to enable increased commercial investment and to transition to more public-private partnership models. For example, the Agency has begun to transition from a model where NASA provides payload integration and other services to one where those services can be purchased from many commercial partners.

As we consider the future of the ISS and U.S. leadership in space, it is helpful to review the benefits provided by U.S. leadership in LEO to exploration, space commercialization, and terrestrial applications.

Preparing for Human Deep Space Missions

In order to prepare for human expeditions into deep space, the Agency must first conduct breakthrough research and test the advanced technology necessary to keep crews safe and productive on long-duration space exploration missions. On-orbit platforms are necessary to mitigate 22 of the 33 human health risks in the portfolio identified by NASA's Human Research Program in support of current and future deep space missions. The research to mitigate these risks must continue beyond 2025 to ensure that we learn what is necessary to travel deeper into space and to live and work in microgravity for long durations. This requirement will not go away no matter what orbital platforms are used.

NASA also plans to continue to use LEO facilities as testbeds to fill critical gaps in technologies that will be needed for long-duration deep space missions. For example, elements of the ISS life support and other habitation systems will be evolved into the systems that will be used for deep space exploration missions and undergo long-duration testing. It is NASA's plan to first develop and demonstrate many critical technology capabilities using LEO platforms prior to deploying these capabilities beyond LEO. This approach is much more cost-effective and faster than conducting this research in cislunar space because of the risks inherent in operating so far from the Earth.

As both research and technology development requirements evolve, NASA will look to take advantage of additional platforms in LEO as a way to accelerate development timetables. If there are cheaper and more efficient ways to meet these requirements, NASA is prepared to utilize them.

Enabling a LEO Commercial Market

NASA's vision for LEO is a sustained U.S. commercial human spaceflight marketplace where NASA is one of many customers. We envision multiple privately-owned/operated platforms – human-tended, permanently-crewed, or robotic – together with transportation capabilities for crew and cargo that enable a variety of activities in LEO, where those platforms and capabilities are sustained to a greater degree than today by commercial revenue. These future platforms may either leverage ISS or be free-flying. This flexibility allows the private sector to determine how best to meet the market demand rather than have the Government dictate how to meet this demand.

NASA must also communicate our forecasted needs in LEO to allow the private sector to anticipate that demand in their business cases. The Administration has proposed 2025 as the date by which direct

Federal support of ISS will end; setting this date provides market clarity for our commercial LEO supply partners. At the last National Space Council meeting at Kennedy Space Center, the Vice President asked the NASA Administrator to work with the secretaries of State and Commerce to develop a strategy for how we can further enable cooperation with our international and private industry partners to continue to develop the infrastructure and policies necessary to spur economic growth in space. That work is ongoing and we plan to deliver some of those recommendations at the fall meeting of the Council.

In this vision, NASA would be able to share the cost of LEO platforms with other commercial, Government, and international users. This would allow NASA to maximize its resources toward missions beyond LEO, while still having the ability to utilize LEO for its ongoing needs for research, training, and technology development.

In order to enable this vision, NASA is not only executing several public-private partnerships, currently centered around the ISS, to foster the development of customers for LEO capabilities, but also is maturing the supply industry to be able to meet future demands. NASA is also initiating the Commercial LEO Development program to further the development of commercial on-orbit capabilities beyond what is available today through the ISS.

The Commercial Resupply Services (CRS) contracts, the Commercial Crew Program, and the ISS National Laboratory are key complementary activities to enable this vision. Under the CRS contracts, NASA's two commercial cargo partners, Space Exploration Technologies (SpaceX) and Orbital ATK, have demonstrated not only the ability to provide cargo deliveries to ISS, but also the flexibility to recover effectively from mishaps. The addition of the Sierra Nevada Corporation as a third commercial service provider will add significant on-orbit and return capability. Both Orbital ATK and Sierra Nevada Corporation have begun to investigate options to perform significant on-orbit operations after their primary cargo mission is completed. These two providers are able to provide an on-orbit research capability independent of ISS. NASA's commercial crew partners, SpaceX and the Boeing Company, are developing the Crew Dragon and CST-100 Starliner spacecraft, respectively. These companies have made significant progress toward returning crew launches to the U.S., and NASA anticipates having these capabilities in place by 2019 to regularly fly astronauts safely to and from ISS. The crew and cargo vehicles, as well as the launch vehicles developed by these providers, have the potential to support future commercial enterprises as well as ISS.

The Center for the Advancement of Science In Space (CASIS) manages the activities of the ISS National Laboratory to increase the utilization of the ISS by other Federal entities and the private sector. CASIS works to ensure that the Station's unique capabilities are available to the broadest possible cross-section of U.S. scientific, technological, and industrial communities. The ISS National Laboratory is helping to establish and demonstrate the market for research, technology demonstration, and other activities in LEO beyond the requirements of NASA. Commercial implementation partners are now bringing their own customers to LEO through the National Laboratory, as well.

ISS Transition

In the NASA Transition Authorization Act of 2017, Congress requested a plan from NASA to transition ISS from the current regime that relies heavily on NASA sponsorship to a regime where NASA could be one of many customers of a LEO non-Governmental human spaceflight enterprise. NASA has been building a strategy and assessing options that support this vision for the future of human spaceflight in LEO, and this is reflected in the ISS Transition Report, delivered to Congress in late March of this year. NASA anticipates that the ISS is capable of continuing to operate within prudent technical margins and its lifetime could exceed original engineering estimates. This is a testament to American ingenuity and technological prowess.

However, complacency is the enemy of progress in technology development. We must continue to push the boundaries of what we believe is possible, not just for NASA but for the entire space industry. NASA is ready to ensure that LEO is open for American business and that our international partners have a role to play in lunar development. The development of commercial space operations in LEO will benefit NASA as we continue to utilize those capabilities to do the things that only NASA can do in exploration. Those principals are two sides of the same coin – they operate together and are not mutually exclusive.

As we contemplate what will happen in this transition, it is important that we remember lessons learned from the ISS and continue to build on them for the next phase of NASA's involvement in LEO and beyond. This transition is an opportunity to demonstrate to the world that U.S. leadership in space is not about one program, but about the qualities that make us the greatest spacefaring nation on the planet. Our insistence that the industry has the ability to respond to Government imperatives and that our international partners can count on us to lead the next generation of capabilities in LEO and beyond will light the way for this next phase of human exploration.

ISS Transition Principles

Several key principles will be reflected in any strategy or decision regarding the ISS and the future of LEO, as well as NASA's role as one of many customers of services or capabilities that are provided by private industry as part of a broader commercial market. The following principles will ensure uninterrupted access to LEO capabilities and long-term national interests in human space exploration, while supporting national security objectives, such as a competitive industrial base and U.S. leadership:

- Expanding U.S. human spaceflight leadership in LEO and deep space exploration, including continuity of the relationships with our current ISS international partners;
- Increasing platform options in LEO to enable more ISS transition pathways, security through redundant capabilities, and industrial capability that can support NASA's deep space exploration needs;
- Spurring vibrant commercial activity in LEO;
- Continuing to return benefits to humanity through Government-sponsored basic and applied on-orbit research;
- Providing continuity among NASA's LEO, deep space exploration, and development and research activities and missions toward expanding human presence into the solar system;
- Maintaining critical human spaceflight knowledge and expertise within the Government in areas such as astronaut health and performance, life support, safety, and critical operational ground and crew experience;
- Continuing Government-sponsored access to LEO research facilities that enable other Government agencies, academia, and private industry to increase U.S. industrial competitiveness and provide goods and services to U.S. citizens; and
- Continuing to reduce the Government's long-term costs through private industry partnerships and competitive acquisition strategies.

ISS Transition Strategy

As part of a cohesive exploration strategy, NASA intends to meet its needs and requirements in LEO by leveraging private industry capacity, innovation, and competitiveness that could offer the prospect of lower cost to the U.S. Government, while at the same time expanding the economic sphere of U.S. industry into LEO and beyond. This could enable NASA to apply more personnel and budget resources to expanding human space exploration beyond LEO and enhancing U.S. leadership in human spaceflight around the world. Beyond the prospect of lower operational costs for a LEO platform, shifting focus to industry can additionally reduce the infrastructure burden on NASA, which could reduce operations and maintenance costs.

In order to ensure that private industry is prepared to provide the services and capabilities that support NASA's needs in LEO, as outlined in the key principles above, and to enable private industry to develop markets and customers beyond the Government, NASA is proposing the following approach:

1. Begin a step-wise transition of LEO human spaceflight operations from a Government-directed activity to a model where private industry is responsible for how to meet and execute NASA's requirements. Consistent with the *ISS Transition Principles*, this does not mean NASA is "commercializing the ISS." Instead, NASA maintains U.S. Government leadership and responsibilities as outlined in the Partnership agreements, and continues to maintain the essential elements of human spaceflight, such as astronaut safety and the high-risk exploration systems.

   This will give NASA time to engage with industry to begin transforming the many NASA-directed activities that are currently performed through several contracts into more of a public-private partnership and/or services contract(s) model where NASA's current responsibilities are executed and managed by private industry. This time period will also provide the opportunity for NASA and private industry to engage with stakeholders and to only proceed when industry has matured and is capable of executing NASA's requirements. The transition of ISS will ensure that there are private companies with the experience and expertise to operate various types of platforms in LEO by the mid-2020s. This transition to private industry must be done in a cost-effective manner and not exceed current operational costs.

   Consistent with the *ISS Transition Principles*, NASA will continue discussions with the ISS international partners to help shape the long-term future of LEO.

2. Solicit information from industry on the development and operations of private on-orbit modules and/or platforms and other capabilities that NASA could utilize to meet its long-term LEO requirements that are consistent with the *ISS Transition Principles*. The scope of the solicitation may include risk reduction development activities, or modules or elements that could either be attached to the ISS or be free-flying. The solicitation may also include private-industry-conducted studies on the future of the ISS platform that may be combined with private industry objectives in LEO.

   NASA began with a solicitation in FY 2018 to gather broad industry input on interest in meeting NASA's long-term needs and objectives that should lead to multiple awards in FY 2019 funded out of the Commercial LEO Development program.

3. NASA will also be working with the Department of Commerce to investigate opportunities to facilitate and enable private industry to develop new market opportunities in LEO. It is important that U.S. industry discover the global competitive advantage of utilizing space for research and revenue-generation activities. This ultimately allows NASA to be one of many customers.

ISS Considerations and the Eventual Future of the ISS Platform

From a structural integrity analysis standpoint, the ISS platform is expected to have significant structural life well beyond 2028 (based on the current assessment period). Many of the ISS modules, particularly the modules launched in the later years of ISS assembly, are likely to have structural life well into the 2030s. Although it is thus likely technically feasible to continue to operate the ISS well beyond 2028 with continued maintenance, it is also necessary to consider the current high costs of operating this complex facility. The ISS lifetime must also be considered in the context of what our national priorities are for a robust LEO economy. The LEO economy is unlikely to reach its full potential if the Federal Government is the sole supplier of LEO research capabilities.

The future of the ISS will be evaluated using the *ISS Transition Principles* to ensure there is no gap in the availability of a LEO platform to meet NASA's needs, whether this means transitioning the operations of the ISS to private industry through public-private partnership, augmenting the ISS with privately developed modules, combining portions of the ISS with a new private platform, or de-orbiting the ISS and beginning anew with a free-flying platform.

Decisions about the future of the ISS will be discussed across the ISS international partnership. The partners agree on common themes for considering the future of ISS and exploration, including:

- Reducing operational costs;
- Offering frequent visible national astronaut opportunities;
- Continuation and continuity of research and technology development activities;
- Building synergies between LEO and exploration activities; and
- Support of commercial opportunities.

NASA's Long-Term LEO Requirements

NASA and the U.S. have a long history of human spaceflight leadership and LEO research and technology development that go all the way back to the Mercury program through Gemini, Apollo, Skylab, the Space Shuttle, and the ISS.

Regardless of what happens next in this transition, NASA will maintain U.S. leadership in LEO and human spaceflight through lunar exploration as a basis for gaining the knowledge and capabilities for Mars consistent with the *ISS Transition Principles*. Within that context, NASA is planning to continue with the following LEO needs and objectives beyond the life of ISS:

- Maintaining the current ISS international partnership and possibly adding new international and domestic participants;
- Conducting regular LEO crewed operations, including short- and long- duration missions:
  - Enabling operational space proficiency;
  - Shifting from human health and performance countermeasures development (the ISS portion of which is expected to be complete by 2024) to validations of integrated long-duration systems, habitation, operations, and crew isolation;
- Developing and demonstrating long-term technology/systems (e.g., life support);
- Conducting space life and physical sciences basic and applied research at current level and capabilities;
- Conducting National-Laboratory-based research and technology development; and
- Providing opportunities for astrophysics, space, and Earth science research.

These long-term requirements, while similar to that of the current ISS Program, could be met with various types of modules or platforms that do not necessitate a vehicle (or vehicles) as complex as the ISS. Many of the research activities could be conducted on shorter-duration platforms, similar to the Space Shuttle, or even crew-tended platforms.

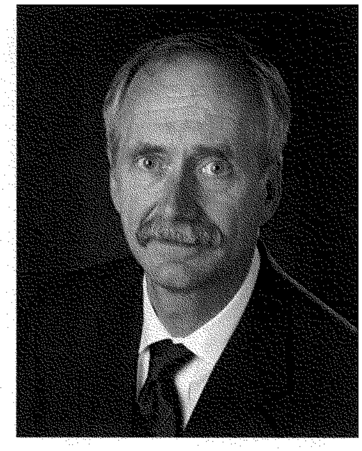
Fast Forwarding to the Mid-2020s

Continuing with current policies, including the Commercial LEO Development program, NASA can project what the LEO landscape may look like in the mid-2020s. We will maintain our strong global leadership position in LEO, starting with the continuation of the ISS through 2024, the validation of commercial cargo and crew transportation costs, and the completion of many NASA exploration-related human and systems research and demonstration activities. Through the commercial LEO development program, we hope to have in operation multiple alternatives to the current model of space station operations that can both meet growing commercial needs and meet Government needs at a lower total cost to the Government than exists today.

Conclusion

NASA looks forward to working with Congressional stakeholders, researchers, private industry, and our ISS international partners on the future of the ISS and LEO, to ensure that the U.S. maintains our human spaceflight leadership.

Mr. Chairman, I would be happy to respond to any questions you or the other Members of the Committee may have.



WILLIAM H. GERSTENMAIER
ASSOCIATE ADMINISTRATOR FOR
HUMAN EXPLORATION AND OPERATIONS

William H. Gerstenmaier is the associate administrator for the Human Exploration and Operations Mission Directorate at NASA Headquarters in Washington, DC. In this position, Mr. Gerstenmaier provides strategic direction for all aspects of NASA's human exploration of space and cross-agency space support functions of space communications and space launch vehicles. He provides programmatic direction for the continued operation and utilization of the International Space Station, development of the Space Launch System and Orion spacecraft, and is providing strategic guidance and direction for the commercial crew and cargo programs that will provide logistics and crew transportation for the International Space Station.

Mr. Gerstenmaier began his NASA career in 1977 at the then Lewis Research Center in Cleveland, Ohio, performing aeronautical research. He was involved with the wind tunnel tests that were used to develop the calibration curves for the air data probes used during entry on the Space Shuttle.

Beginning in 1988, Mr. Gerstenmaier headed the Orbital Maneuvering Vehicle (OMV) Operations Office, Systems Division at the Johnson Space Center. He was responsible for all aspects of OMV operations at Johnson, including development of a ground control center and training facility for OMV, operations support to vehicle development, and personnel and procedures development to support OMV operations. Subsequently he headed the Space Shuttle/Space Station Freedom Assembly Operations Office, Operations Division. He was responsible for resolving technical assembly issues and developing assembly strategies.

Mr. Gerstenmaier also served as Shuttle/Mir Program operations manager. In this role, he was the primary interface to the Russian Space Agency for operational issues, negotiating all protocols used in support of operations during the Shuttle/Mir missions. In addition, he supported NASA 2 operations in Russia, from January through September 1996 including responsibility for daily activities, as well as the health and safety of the NASA crewmember on space station Mir. He scheduled science activities, public affairs activities, monitored Mir systems, and communicated with the NASA astronaut on Mir.

In 1998, Mr. Gerstenmaier was named manager, Space Shuttle Program Integration, responsible for the overall management, integration, and operations of the Space Shuttle Program. This included development and operations of all Space Shuttle elements, including the orbiter, external tank, solid rocket boosters, and Space Shuttle main engines, as well as the facilities required to support ground processing and flight operations.

In December 2000, Mr. Gerstenmaier was named deputy manager, International Space Station Program and two years later became manager. He was responsible for the day-to-day management, development, integration, and operation of the International Space Station. This included the design, manufacture, testing, and delivery of complex space flight hardware and software, and for its integration with the elements from the International Partners into a fully functional and operating International Space Station.

Named associate administrator for the Space Operations Mission Directorate in 2005, Mr. Gerstenmaier directed the safe completion of the last 21 Space Shuttle missions that witnessed assembly complete of the International Space Station. During this time, he provided programmatic direction for the integration and operation of the International Space Station, space communications, and space launch vehicles.

In 2011, Mr. Gerstenmaier was named to his current position as associate administrator for the Human Exploration and Operations Mission Directorate.

Mr. Gerstenmaier received a bachelor of science in aeronautical engineering from Purdue University in 1977 and a master of science degree in mechanical engineering from the University of Toledo in 1981. In 1992 and 1993, he completed course work for a doctorate in dynamics and control with emphasis in propulsion at Purdue University.

Mr. Gerstenmaier is the recipient of numerous awards, including three NASA Certificates of Commendation, two NASA Exceptional Service Medals, a Senior NASA Outstanding Leadership Medal, the Meritorious Executive Presidential Rank Award, and Distinguished Executive Presidential Rank Award. He also was honored with an Outstanding Aerospace Engineer Award from Purdue University. Additionally, he was twice honored by Aviation Week and Space Technology for outstanding achievement in the field of space. His other awards include: the AIAA International Cooperation Award; the National Space Club Astronautics Engineer Award; National Space Club Von Braun Award; the Federation of Galaxy Explorers Space Leadership Award; AIAA International Award; the AIAA Fellow; Purdue University Distinguished Alumni Award; and honored at Purdue as an Old Master in the Old Masters Program; recipient of the Rotary National Award for Space Achievement's National Space Trophy; Space Transportation Leadership Award; the AIAA von Braun Award for Excellence in Space Program Management; and the AIAA von Karman Lectureship in Astronautics.

He is married to the former Marsha Ann Johnson. They have two children.

October 2015

Chairman SMITH. Thank you, Mr. Gerstenmaier.
And Dr. Lal?

TESTIMONY OF DR. BHAVYA LAL, RESEARCH STAFF, SCIENCE AND TECHNOLOGY POLICY INSTITUTE FOR DEFENSE ANALYSIS

Dr. LAL. Chairman Smith, Ranking Member Johnson, Chairman Babin, Ranking Member Bera, and members of the committee, thank you for the opportunity to testify today.

NASA's fiscal year 2019 budget proposes to end direct financial support for the International Space Station by 2025 and transition to a commercially operated low-Earth orbit capability. This transition can occur in two primary ways. The ISS can be privatized, as in all or parts of it can be taken over by a private entity and operated on behalf of the government, much like most DOE labs are today. Alternatively, a private-sector entity could build, launch, and operate a commercial LEO-based platform for profit.

In a recent study conducted at the Institute for Defense Analysis Science and Technology Policy Institute, my colleagues, including Keith Crane, Benjamin Corbin, Reina Buenconsejo, and I addressed this second option. Could a privately owned and operated permanently crewed space station that will look nothing like the ISS generate sufficient revenues to cover its capital and operations costs without government subsidies? Our analysis identified 21 activities that could generate revenues from commercial or government customers on a LEO platform. We interviewed over 70 subject matter experts and built models to estimate the potential revenues that could be generated for each activity. We also estimated the cost of two possible configurations of a station that could house all of these activities.

Our estimates of revenues and costs incorporated many assumptions, the most critical of which was a 50 to 75 percent reduction in the price of launch in the 2025-and-beyond time frame. Even with these aggressive assumptions, and three of the four scenarios we postulated, revenues did not cover costs. Venture capitalists we spoke to indicated that projected revenues streams are too far in the future and too uncertain to warrant making significant investments to date. Overall, our analysis showed that it is unlikely that a commercial space station would be economically viable by 2025.

There are some caveats that go with the finding. Some markets for space station-based products and services could experience more rapid growth than we assumed, and revenues could be greater than estimated. There is also a risk that products or services that are projected to generate large revenues might fail to do so. The growing availability of suborbital and parabolic flight opportunities, as well as temporary un-crewed orbital capsules could both take away potential business away from a permanent station and at the same time provide an onramp to develop new markets.

Last but not least, possible future Chinese or Russian space stations subsidized by their respective governments could also draw business opportunities away from a private space station.

If a permanently crewed commercial space station in LEO is a critical element of United States leadership in space, without a ready commercial case in place by 2025, there are at least three options that merit further exploration. The ISS could be extended through 2028. Continuing to operate, maintain, and resupply the station will cost about $3–4 billion a year, which would take resources away from deep space exploration and affect the timeline for a return of U.S. astronauts to the Moon. It may also take away opportunities from a rapidly burgeoning private sector that feels ready to lead activities in LEO.

The ISS or modules within it could be privatized with a private-sector entity operating the station but paid for largely by the government. Depending on how the deal is structured, this could in principle yield cost savings, although that cannot be assumed. As interviewees in our study indicated, the station was not designed to be operated inexpensively, and maintenance costs are likely to increase as elements are operated past their design lifetimes.

Third, NASA could select a private entity to operate a commercial platform and rent space or request services as a tenant. While this option is best suited to help LEO commercialization, it will likely require some level of a government subsidy for the commercial operator. In our analysis, an annualized payment of about $2 billion could cover the cost of the platform even in the case of zero revenues. A deeper dive into the tradeoffs among these options may be crucial before any permanent decisions on America's post-2024 LEO plans can be made.

Thank you for the opportunity to share our analysis, and I look forward to any questions you have.

[The prepared statement of Dr. Lal follows:]

Testimony before the Subcommittee on Space, Committee on Science, Space, and Technology, U.S. House of Representatives

Hearing on America's Human Presence in Low-Earth Orbit
Dr. Bhavya Lal, IDA Science and Technology Policy Institute
May 17, 2018

Chairman Babin, Ranking Member Bera, and distinguished Members of the Committee, thank you for the opportunity to testify today.

NASA's FY19 budget proposes to end direct financial support for the International Space Station (ISS) by 2025, and transition to a commercially-operated Low-Earth Orbit (LEO) capability, essentially turning NASA from a landlord to a tenant in LEO. This transition can occur in two primary ways. The ISS could be *privatized*, as in all or parts of it could be taken over by a private entity, and operated on behalf of the government, much like most DOE labs are today. Alternatively, a private sector entity could build, launch, and operate a *commercialized* LEO-based platform for profit.

In a recent study conducted at the Institute for Defense Analyses (IDA) Science and Technology Policy Institute, my colleagues including Keith Crane, Benjamin Corbin, Reina Buenconsejo and I addressed this second option: Could a privately owned and operated, permanently-crewed space station, that may look nothing like the ISS, generate sufficient revenues to cover its capital and operations costs, without government subsidies?[1]

Assessment of the Market Case for a Private Space Station

For the purpose of the study, we assumed that a private space station would be wholly owned and operated by private parties who would decide the station's capabilities, the markets it would serve, and the prices it would charge for its services. The private parties' customers could be commercial or government entities—whoever would be willing to pay for the services provided by the station. Additionally, we assumed that the space station would need to be human-tended or human-inhabited, located in LEO, and able to engage in many revenue-generating activities.

We identified activities that could generate a revenue stream for the station. We modeled the station as an industrial park in space, where researchers, astronauts, businesses, and non-profit organizations rent parts of the station to conduct their activities. We then generated estimates of revenues that the space station could earn by leasing space or

[1] The report is available at https://idalink.org/P8247

providing services in support of these. Activities related to media, advertising, and education were developed with input and review from experts employed at the global communications and advertising agency firm Saatchi & Saatchi in New York. For each activity, we made assumptions that generated lower revenue projections based on less optimistic assumptions and higher revenue based on more optimistic assumptions. We summed the lower projections to generate an aggregate "low" estimate and summed the higher projections to generate an aggregate "high" estimate. If a private space station were to be built, actual revenues could be lower or higher than either of the projections presented in my testimony.

To generate these estimates, all in constant 2015 dollars, we held discussions with over 70 individuals engaged in activities in space or with detailed knowledge of such activities. In many cases, activities (and their costs) on the ISS were used as points of departure, with appropriate adjustments for private sector operations. Using information from these individuals and from other sources on market size, competing technologies, and costs of conducting the activity on a space station in LEO, we developed individual methodologies to estimate revenues from each activity for the space station.

We selected concepts of space stations that might best serve the activities identified and generate revenues. For each of the selected space station concepts, we generated parametric cost models, and used engineering design parametric relationships to estimate the costs of developing and constructing the station, the costs of operations once built, and costs of resupply and personnel. We then compared annualized costs to potential revenue streams to determine if prospective revenues might be sufficient to cover a station's costs and potentially attract private investment.

The analysis incorporated many assumptions, the most critical of which was a major reduction in the price of launch in the timeframe from 2025 and beyond. We assumed launching an astronaut would be priced at about $20 million, a reduction of over 75 percent compared to the current price of launching U.S. astronauts on Russian spacecraft; encapsulated cargo, at $20,000 per kilogram (kg), a decrease of about 66 percent from the current price; full launch, at $62 million, a reduction of about 50 percent; and propellant transport, $5,000 per kg, a service for which there is currently no price because it is not yet available.

STPI identified 21 activities that have the potential to generate revenues on a private LEO space station. The activities fell into five categories:

- Human habitat or destination for private space flight participants or government astronauts

- Activities supporting the satellite sector, especially on-orbit assembly of satellites
- Manufacturing products and services for use in space and on Earth, especially high-grade silicon carbide and exotic fiber optic cable
- Research and development (R&D), testing, and Earth observation
- Media, advertising, and education

We ruled out products such as growing human organs in space that we believe are more than a decade away from becoming a reality. Markets like these or others we have not encountered in our research may emerge, generating revenues not included in this analysis. Some markets for space station-based products and services could experience much more rapid growth than we have assumed here. Conversely, there is the risk that products or services projected to generate large revenues fail to do so. R&D efforts may make it possible to develop products on Earth or on high-altitude controlled, suborbital, or parabolic platforms at lower cost rather than producing those products on orbit.

Other challenges make our projections uncertain. For example, we do not yet know the extent to which potential future Chinese or Russian space stations might draw away opportunities from a U.S. private space station.

The low estimate for total annualized revenues from activities conducted on a space station is $455 million and the high estimate is $1,187 million. Figure 1 below shows the low and high revenue estimates for each activity, and Figure 2 shows the combined estimates for low and high revenues. Figure 2 also highlights that two categories of activities account for most of the projected revenues. For the high estimate (right column, Figure 2), manufacturing products in space is the largest contributor to overall revenues, accounting for nearly 35 percent. Potentially profitable manufacturing operations for exotic optical fibers drive these revenues. Revenue from satellite support—specifically assembly in orbit—was a close second, at 30 percent of total revenues. In the case of the low estimate (left column), the manufacture of exotic optical fibers alone accounted for over half of total revenues.

U.S. Government activities—principally government astronauts, R&D, and assembly of government satellites—comprises 14–39 percent of the revenues in low and high scenarios. NASA in particular pays the station operator at least $40 and $80 million for services rendered in the low and high estimates, respectively; these payments do not include other expenses such as transportation to the station for sovereign astronauts or research experiment development costs. NASA does not pay more for services than other customers do for the same services, nor does NASA act as an anchor tenant.

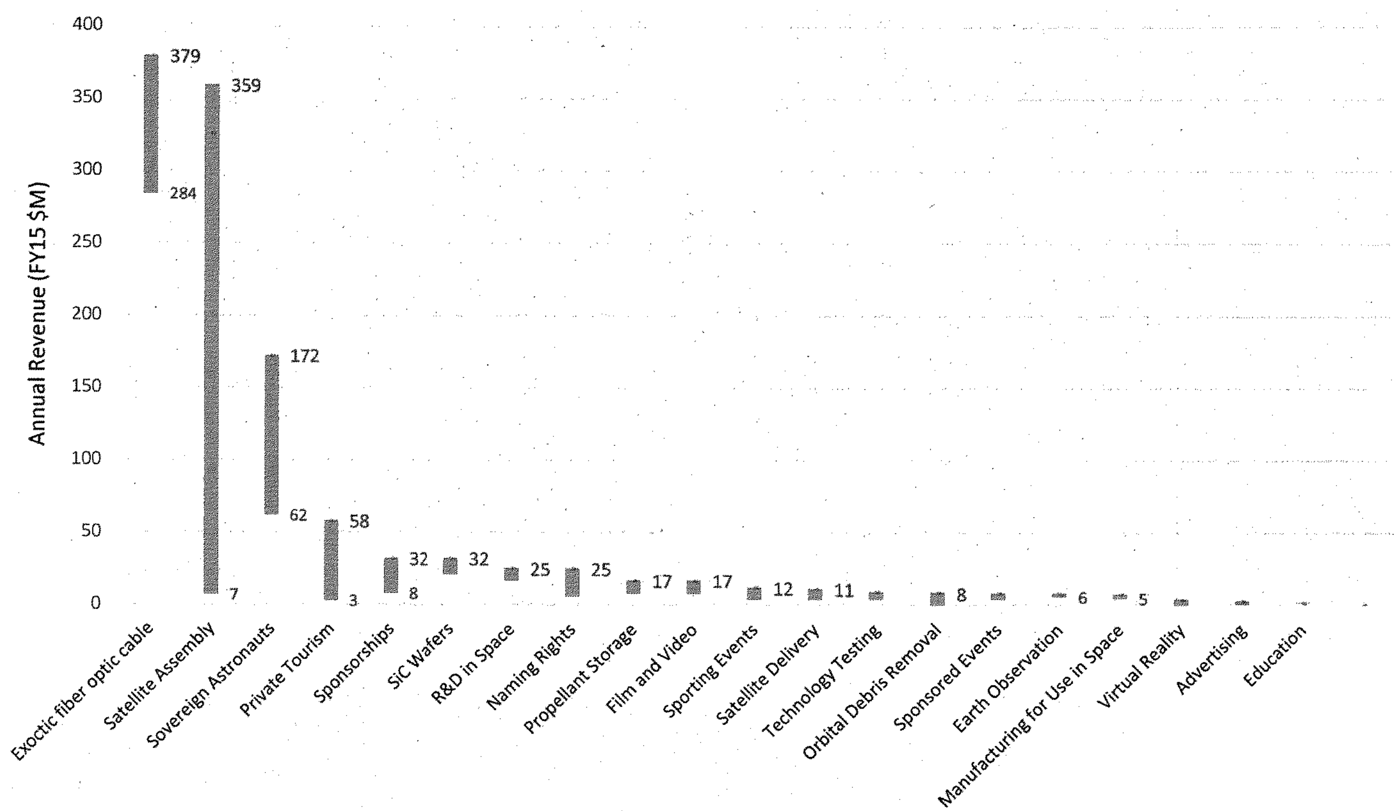


Figure 1. Projected Revenues for a Private Space Station (FY15 Millions of Dollars)

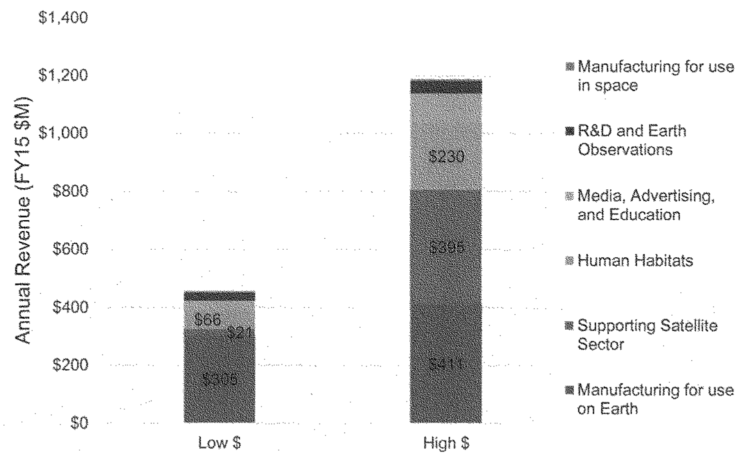


Figure 2. Distribution of Projected Annual Revenues for the Space Station

Note: Numbers may not add up due to rounding

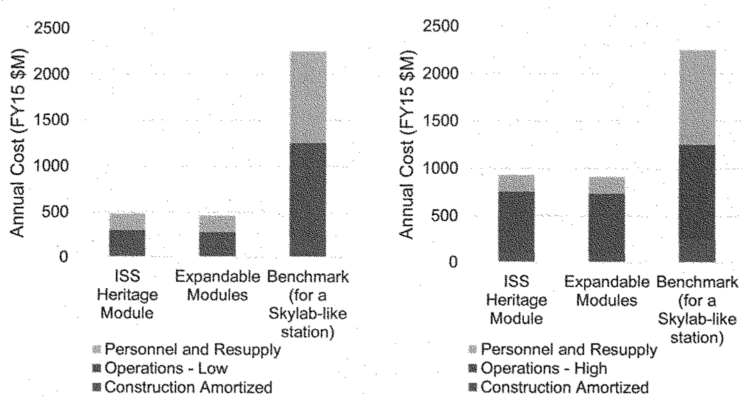


Figure 3. Comparison of Low (left) and High (right) Estimated Annualized Costs of Three Private Station Concepts

These revenue estimates are highly uncertain, and based on extrapolations from current conditions, as they are for revenues 10 years from 2016. The estimates should not be considered lower or upper bounds; rather, they represent our best attempts to provide data-driven estimates of potential revenues based on different sets of assumptions. The difference between our low estimate and high estimate is large—$732 million. This substantial difference reflects the highly tentative nature of these estimates.

While the projections are per force speculative, they do provide empirically-based assessments of almost all of the activities that have been discussed as potential revenue sources for a privately-owned and operated space station. These estimates are designed to help policymakers assess the prospects that the private sector might invest in such endeavors.

We evaluated several prospective concepts for a space station that could house all the activities for which we generated estimates of potential revenues, and estimated the costs of two of them: a space station constructed from ISS-heritage modules, and a space station constructed from expandable modules. In addition, we used a publicly available estimate of the costs of a Skylab-like station as a benchmark.

The comparison of low and high estimated annualized costs of the three private station concepts shows a breakdown of estimates of costs for all three concepts for three elements: (1) the costs of designing and constructing the modules, (2) annual costs of operations, and (3) costs to the station owner of transporting their astronaut employees to and from the station and resupplying the station (Figure 3). For ease of analysis and based on precedent, construction costs are amortized over 10 years. For operations costs, as a result of the lack of consensus among our interviewees, we generated a low and a high estimate. As the figure below indicates, the annualized low estimate cost of a private space station was $463 million, and the high, our benchmark, was $2.25 billion.

Figure 4 maps the low and high estimates of annual revenues and annualized costs for the station. As can be seen, even in a best-case scenario where launch costs are significantly lower than they are today, and other optimistic assumptions, neither estimate of annual revenues covers the estimate of annualized costs for the high estimate (our benchmark). Out of the four cases, only in the high-revenue, low-cost scenario do revenues exceed costs.

We conducted a simple financial analysis to determine whether a station might generate a sufficiently high rate of return to attract private investors. For the instances in which station costs were low (the higher cost scenario ended up losing money), we calculated the internal rates of return for a prospective privately owned and operated space station. In the case of high revenues and low construction and low operations costs ($200 million), the internal rate of return is 40 percent, exceeding even the highest venture capital fund hurdle rate. When we use high revenue and low construction costs but high operations costs ($650 million), the internal rate of return falls to 18 percent. The station loses money in the other scenarios. *Venture capitalists whom we interviewed noted that the projections of revenues and costs are so uncertain that they would* *have no interest in financing a space station until projected revenues from these activities show signs of materializing.*

We also conducted sensitivity analyses on launch costs, a major driver of both revenues and costs. As Figure 5 shows, if launch costs were to fall further, either as a result of a technology breakthrough or a government subsidy, the estimates of revenues for the low-cost scenario would increase by 23 to 53 percent, for the high- and low-revenue scenarios, respectively. If the government subsidizes launch costs entirely—as it does today for many activities on the ISS—revenues for a private space station would go up by 46 to 106 percent, for the high- and low-revenue scenarios, respectively. These subsidized revenue estimates do not take into account a potential increase in demand due to a lower cost to access the station.

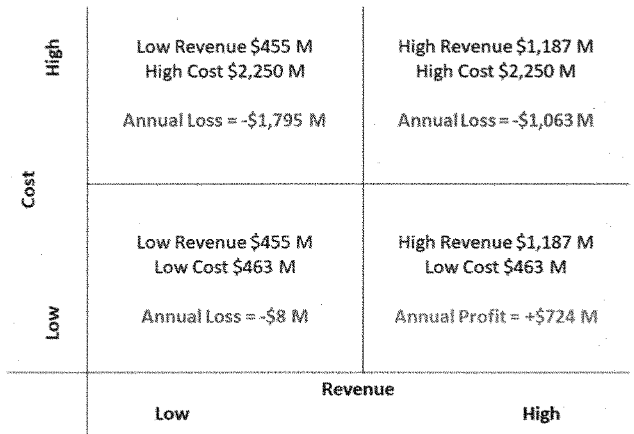


Figure 4. Estimated Annualized Cost and Revenue Estimates for a Private Space Station

In our interviews with the venture capital community, we learned that revenue streams were seen as too far out in time and too uncertain to warrant venture capital or angel investment, although a wealthy philanthropist might choose to self-finance the project. *In our estimation, it is unlikely that a commercially owned and operated space station will be economically viable by 2025.*

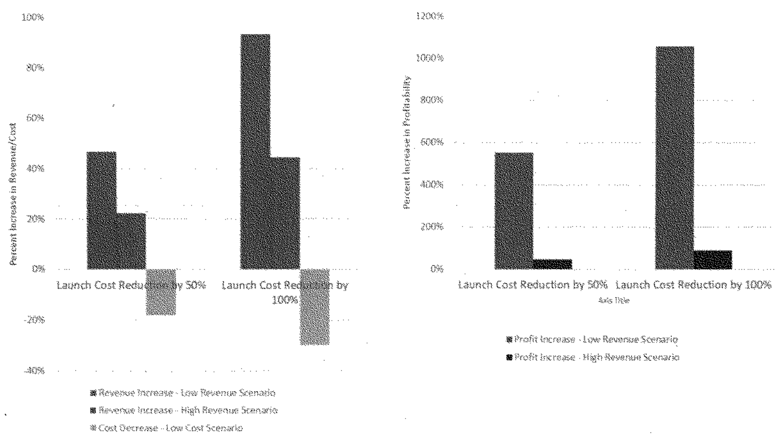


Figure 5. Effect of Reduced Launch Cost on Revenues, Cost, and Profitability

Conclusion

There are some caveats that go with the findings. Some markets for space station-based products and services could experience more rapid growth than we assumed, and revenues could be greater than estimated. There is also a risk that products or services that are projected to generate large revenues might fail to do so. For example, new manufacturing techniques to produce goods terrestrially that can currently *only* be produced in microgravity would drastically change the analysis, making it more difficult for a private space station to generate profit. The growing availability of suborbital and parabolic flight opportunities, as well as temporary, uncrewed orbital capsules, could both take potential business away from a permanent station *and* provide an on-ramp to develop new markets. Last but not least, possible future Chinese or Russian space stations, subsidized by their respective governments, could also draw business opportunities away from a private space station.

If a permanently-crewed commercial space station in LEO is a critical element of United States' leadership in space, without a ready commercial case in place by 2025, there are several options that merit further exploration:

- The ISS could be extended through 2028. Continuing to operate, maintain and resupply the station will cost about $3–4 billion a year, which would take resources away from deep space exploration, and affect the timeline for the return of U.S. astronauts to the

Moon. It may also take away opportunities from a rapidly burgeoning private sector that feels ready to lead activities in LEO.

- The ISS or modules within it could be privatized. Depending on how the deal is structured, this could in principle yield cost savings, although that cannot be assumed. As interviewees in our study indicated, the station was not designed to be operated inexpensively, and maintenance costs are likely to increase as elements are operated past their designed lifetimes. Privatization would entail additional challenges. For example, we have commitments to international partners, and their views would need to be considered.

- NASA could select a private entity to operate a commercial platform at an inclination and orbit that maximizes their potential profit. While this option is best suited to help LEO commercialization, it will likely require some level of a government subsidy for the commercial operator. *In our analysis, an annualized payment of about $2 billion could cover the cost of a private station even in the case of zero revenues.*

A deeper dive into the trade-offs among these options may be crucial before any permanent decisions on America's human presence in LEO can be made. And regardless of the pathway chosen, the ISS needs to be doing everything it can today to help private companies reduce risk in profit-making activities in space.

I'd like to conclude my remarks by observing that there are likely many technological, legal, regulatory and international challenges at this time of transition. I am confident however that the United States will overcome these challenges through its ingenuity, daring, and ambition, attributes I consider core to the American space enterprise.

Thank you!

Bhavya Lal, Ph.D., is a researcher at the IDA Science and Technology Policy Institute (STPI), a Federally Funded Research and Development Center established by Congress to support the White House Office of Science and Technology Policy (OSTP) and other executive branch agencies. At STPI, Dr. Lal leads analysis of space technology, strategy, and policy for OSTP, the National Space Council, NASA, the Office of the Director of National Intelligence, Federal Aviation Administration, and other space-oriented Federal agencies and departments. Before joining STPI, Dr. Lal was president of C-STPS LLC, a science and technology policy research and consulting firm. Prior to that, she was the Director of the Center for Science and Technology Policy Studies at Abt Associates.

She is currently the co-chair of the National Academy of Science (NAS) Committee on the State of U.S. Electronic Parts Radiation Testing Infrastructure for Space Applications, and was previously vice-chair and member of NAS committees on Achieving Science Goals with CubeSats and 3D Printing in Space, respectively. She serves on the NOAA Advisory Committee on Commercial Remote Sensing (ACCRES), and on the UN Committee on Space Research (COSPAR) to develop an international scientific roadmap for small satellites. She co-organizes a seminar series on space history and policy with the Smithsonian National Air and Space Museum.

Dr. Lal holds B.S. and M.S. degrees in nuclear engineering from the Massachusetts Institute of Technology (MIT), a second M.S. from MIT's Technology and Policy Program, and a Ph.D. in Public Policy and Public Administration (Science and Technology Policy) from George Washington University.

Chairman SMITH. Thank you, Dr. Lal.
And Dr. Cantwell?

TESTIMONY OF DR. ELIZABETH R. CANTWELL, CEO, ARIZONA STATE UNIVERSITY RESEARCH ENTERPRISE (ASURE); PROFESSOR OF PRACTICE, SCHOOL FOR ENGINEERING OF MATTER, TRANSPORT & ENERGY, ARIZONA STATE UNIVERSITY

Dr. CANTWELL. Good morning, Chairman Smith, Ranking Member Johnson——

Chairman SMITH. Is your mic totally on there?

Dr. CANTWELL. Good morning.

Chairman SMITH. There it is.

Dr. CANTWELL. Sorry, I always hear myself as very loud.

Chairman Smith, Ranking Member Johnson, good morning. Members of the Committee, Mr. Babin, Mr. Bera, it's a pleasure. Thank you for inviting science to the table. I appreciate the opportunity to submit testimony and participate in the discussion.

This is timely as the science community has just seen the delivery of the National Academies' report, a midterm assessment of implementation, and of the decadal survey of life and physical sciences research at NASA, which reviews the health and progress of the life and physical microgravity science portfolio in space.

I was Chair of the original decadal science study, which was delivered in 2011, and I currently sit on the Oversight Committee for this science portfolio within the National Academies. And I'm also a Chair of the National Academies' Science and Engineering Board. So I make the following comments.

The United States is not conducted human operations on an extraterrestrial planetary body for close to 50 years. The opportunity to do this again and to have a meaningful life and physical sciences research program that enhances our ability to go back to the lunar surface and even further is frankly thrilling. The Committee has heard a lot over the years about how the NASA-funded portfolio of life and physical sciences and microgravity has enabled our exploration missions, brought value to our lives on Earth and brought entirely new discoveries that have yielded new thinking for space and terrestrial efforts.

Today, I'll discuss the implications of a potential shift to private-sector platform providers as part of an increasingly privatized LEO ecosystem and how this might be part of a continuing and successful microgravity sciences program if properly incentivized.

The ISS is now a fully functioning science laboratory. It has a well-trained crew that understands the conduct of science. NASA has invested millions in building world-class research hardware assets. We should not waste these assets.

It's additionally true that some microgravity and human spaceflight-related studies may well be suited for platforms other than the International Space Station, particularly if other long-duration platforms are available. Understanding the full cost of research asset investment, especially in the context of potential new costing and pricing paradigms that could be created during a transition from NASA-funded International Space Station to some of the options that Dr. Lal talked about should be developed for NASA-supported science and technology in LEO and should enable a range of space platforms, analogs, and even ground-based facilities.

So far, it is almost always the case for discovery science and for unique mission-focused investigations, as NASA's exploration mission needs are, there is no commercial poll for the microgravity research portfolio. If NASA intends to purchase ISS or long-term LEO capabilities, what is now important is that microgravity exploration research be part of a coherent transition plan, a plan that understands that business models for research are not the same as those driving commercial interests and a plan that recognizes the different perspectives on incentives for research. This could prevent unanticipated and frankly unrecoverable gaps in research capacity, and I particularly focus on the development of STEM workforce associated with those capacities.

Finally, ISS research has not yet completely addressed the highest priorities of our decadal studies. The mid-decadal, which was published just recently, categorically finds that long-term microgravity studies are still lacking. Quoting from that study, "With the totality of human exploration experience beyond LEO restricted to the Apollo era and the limited number of long-duration experiments conducted to date on the International Space Station, the need for microgravity and radiation space science is a strong now as ever."

For exploration missions beyond LEO, we still need to better understand and better mitigate the long-term effects of spaceflight environments on both the biological and physical systems involved in extended missions in deep space and enabling operations in human performance without resupply on timescales measured in years. There is absolutely a need for integrated long-duration experimentation well beyond 2024.

As stakeholder conversations are developed regarding this ISS transition process, we feel it's critical to include our research community, especially as decisions about new commercial pricing structures are made.

Thank you very much for the opportunity.

[The prepared statement of Dr. Cantwell follows:]

America's Human Presence in Low Earth Orbit

Statement by

Elizabeth R Cantwell, Ph.D.
CEO, Arizona State University Research Enterprise and
Professor of Practice, Fulton Schools of Engineering
Arizona State University

Before the

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

May17, 2018

Chairman Smith, Ranking Member Johnson, and Members of the Committee:

I appreciate the opportunity to submit testimony and participate in the discussion surrounding the microgravity space science research portfolio and the transition of ISS to a new LEO landscape after 2024. This is a very important subject and the discussion is timely as we have just seen the delivery of the National Academies report, *A Midterm Assessment of Implementation of the Decadal Survey on Life and Physical Sciences Research at NASA*, which reviews the health and progress of the life and physical microgravity sciences portfolio.

I have phenomenal colleagues at Arizona State University where I work, and I have been privileged to work with literally hundreds of microgravity scientists and engineers in National Research Council studies, but I speak to you today from my personal perspective. I am a space systems engineer with experience on teams that built and operated the Space Shuttle, the ISS and a number of non-crewed satellite missions. My life's work has focused exclusively on enabling great science, big ideas and the implementation of large, complex systems. My comments today are informed not only by my engineering experiences, but also by roles I have played in advising NASA exploration programs. I was Co-Chair of the National Research Council[1] Committee that produced the decadal survey report *"Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era,"* published by the National

---

[1] Now more commonly referred to as The National Academies of Sciences, Engineering and Medicine.

Academies in 2011[2] (referred to hereafter as the Decadal or Decadal Survey). This Decadal Survey lays out a comprehensive portfolio of life and physical sciences research that is enabled by spaceflight and that enables further spaceflight exploration. I am also currently the Co-Chair (with Dr. Rob Ferl of the University of Florida) of the National Academies' Committee on Biological and Physical Sciences in Space (CBPSS). Finally, I am Co-Chair of the National Academies' Aeronautics and Space Engineering Board (ASEB).

The US has not conducted human operations on an extraterrestrial planetary body for close to 50 years. The opportunity to do this again, and to have a meaningful life and physical sciences research program that enhances our ability to go back to the Lunar surface and even further, is thrilling. This committee has heard a great deal over the years about how the NASA-funded portfolio of life and physical sciences in microgravity has enabled our exploration missions, brought value to our terrestrial lives and delivered entirely new discoveries that have yielded new thinking for space and terrestrial endeavors. Under discussion today, and highlighted in these transition hearings, is a shift to private-sector platform providers as part of an increasingly privatized LEO ecosystem that could clearly be part of a successful microgravity sciences program if properly incentivized.

My comments are guided by the following questions.

1) What would be the implications for basic research, its application to deep space exploration, the pipeline of microgravity research and development, and the next generation of space biology and physical scientists if this transition failed to adequately accommodate these S&T areas?
2) To what extent has the existing ISS facility supported research requirements, and what is needed going forward? Are there any areas where the ISS has fallen short in meeting the needs of the research community?
3) What do you see as the opportunities and challenges for the future of space life and physical sciences under the ISS Transition Report scenarios, and what needs to be considered in order to support a successful transition of the research to an alternative platform or operating module?
4) Prior to 2024, are there ways in which NASA can begin to reduce the costs of supporting its research and technology development requirements in LEO, without sacrificing the quantity and quality of that research?

My comments emphasize space life and physical sciences as they enable exploration, but I would be remiss if I did not point out that microgravity research has delivered clear benefits for Earth and is an equally important part of NASA's work to advance the frontiers of science.

The "Recapturing a Future for Space Exploration" Decadal Survey provides a comprehensive set of research priorities for the space life and physical sciences. While an entire chapter (Chapter 11) is dedicated to the capabilities of the ISS, it should be noted that the Decadal recognized that ground-based experiments are necessary in some areas. In addition, it is clear that some

---

[2] https://www.nap.edu/catalog/13048/recapturing-a-future-for-space-exploration-life-and-physical-sciences

microgravity and spaceflight related studies are well suited for platforms other than the ISS, and could just as easily be conducted on other long duration platforms if they were available. Congress should encourage costing and pricing paradigms for NASA-supported S&T that fully enable a range of platforms, analogs and ground based facilities.

The ISS is finally now a fully functioning laboratory. It has a well-trained crew that understand the conduct of science. NASA has invested millions in building world-class research hardware assets (CIR, FIR, Glovebox, rodent habitats, etc.). Keeping these assets in play will be critical for moving research forward in a timely and affordable manner. NASA has increasingly sophisticated onboard analytic capabilities, such as recently demonstrated DNA sequencing. The ISS is equipped with many unique science facilities, launched at great expense but providing considerable payback. Consideration of how to optimally utilize these facilities to serve multiple investigations over many years should be included in our transition thinking.

As commercial platforms emerge, they will be shaped heavily by the demand they anticipate. A commercially operated station catering to pharma research will create a very different capability than one designed to pull fiber optic cables. NASA research has thrived on having a flexible platform and astronaut cohort that can sequence genomes in the morning and conduct combustion experiments in the afternoon. Such breadth of science and technology objectives is critical to responding to exploration needs and scientific opportunities. NASA will need to communicate a clear demand signal for a flexible platform. Otherwise, they may find themselves unable to pursue critical lines of emerging research.

There appears thus far to be little to no commercial pull for the research portfolio our decadal represents – which has largely always been the case for discovery science and exploration mission-enabling investigations. The microgravity science portfolio of the Decadal and Mid-Decadal focus on the human exploration mission and on discovery science. If NASA intends to position itself as a purchaser of ISS or long-term LEO capabilities, rather than having the role of major funder, what is now important is that microgravity exploration research be part of a coherent transition plan, a plan that understands that business models for research are not the same as those driving commercial interest, and a plan that recognizes the different perspectives on incentives for research. This approach would forestall unanticipated and unrecoverable gaps in research capacity (and particularly in workforce development) brought about by incomplete understanding of research requirements for continuity.

In part due to business-model changes, and in part because long-term studies are in their infancy, ISS research has not yet completely addressed the highest priorities of decadal studies. As an example, consistent opportunities for high priority rodent studies have only now been re-initiated after years of funding and capability gaps. With the exception of the final space shuttle flight (STS135 in 2011) NASA didn't sponsor any other rodent research in space for 14-years (2003-2017). CASIS has been able to partially bridge the hiatus with industry-directed research during the past three years using a NASA-developed habitat for mice; however, I note that that industry is under no obligation to fulfill NASA's high priority research needs as specified in decadal studies. ISS is only now (in the past year) giving us regular, longer duration (30-60 day) mouse studies. Rats have yet to fly on the ISS. By way of comparison, STS90 alone flew more than 170 rodents (rats and mice), which is a similar in scope to the past five years of ISS work.

The Mid-Decadal categorically finds that long-term microgravity studies are lacking. Quoting from the Mid Decadal, "With the totality of human exploration experience beyond LEO restricted to the Apollo era, and the limited number of long-duration experiments conducted to date on the ISS, the need for microgravity and radiation science research is as strong now as ever." In reality NASA must seek to better understand and better mitigate the long-term effects microgravity in both the biological and physical systems involved in extended missions in deep space, and do so on the time scale measured in years. This scale of long duration projects on the ISS have yet to occur, creating a need to for integrated long duration experimentation well beyond 2024.

As stakeholder conversations are developed regarding this Transition process, we feel it is critical to include our research community, especially as pricing structure decisions are eventually made.

A robust prioritization scheme that identifies the key research that NASA needs for its deep space program has actually been done in the mandated National Academies studies commissioned to date. What is still needed is NASA clarity in calling out the specific research that needs to completed on ISS for the development of the Gateway. A focused study, to directly answer the question of what research is needed to develop Gateway, could help address this

While transitioning to a commercial LEO ecosystem for NASA is an approach that the National Academies' Committee on Biological and Physical Sciences in Space (CBPSS) has been examining for about 3 years as it affects microgravity research, and is largely supported among the relevant scientific experts, such a transition is fraught with challenges for our research portfolio and community. We see the next 5-6 years as absolutely critical to get right for microgravity science continuity. For example, many in the community do not believe there are cost reduction opportunities as much as cost sharing opportunities. Now is the prime of the ISS's life. If we fail to make the best and fullest use of this station in its current configuration, we will not plant the seeds necessary for future growth under a more commercial model. The opportunity is to look at how the cost of research can be shared with new partners and in payment for sharing the cost, sharing the opportunity that research delivers. Right now, the biggest cost of research is launch and operations costs – this is where a full cost approach will best help determine how NASA can create new business models for research that help us all understand how to mitigate the largest space-based cost of research, which are launch, in-space operations and downmass.

Summary and conclusions:
As stakeholder conversations are developed regarding this Transition process, we feel it is critical to include our research community, especially as pricing structure decisions are eventually made.

What could be done to mitigate some of the issues I have discussed?

- Congress can work with NASA to develop new funding mechanisms for commercial/university partnerships. Part of this transition, to assure that it goes well, should broadly strengthen the relationship between university research and the growing LEO commercial sector through real, meaningful incentives – as we have heard ESA does where LEO contracts are contingent on including a university partner for some research.

- The greatest ambiguity in the transition plan is operational (including launch and timely and reliable down-mass) costs. It would be very useful to commission a full-cost-accounting study for the needed research, to create an honest picture of transferability of a research portfolio to commercial LEO. Such a full-cost accounting approach for the needed research would allow the entire commercial community to understand and then develop business models that allow NASA and the business community to credibly absorb the cost of research, and the research community to have some ability to have confidence in a future where their research can be conducted.

Biographical Information
Elizabeth Cantwell

Elizabeth R. Cantwell (Betsy) is the **Chief Executive Officer of Arizona State University Research Enterprise (ASURE)**, Arizona State University's applied research arm. Dr. Cantwell is responsible for leading the creation, management and capture of large-scale, externally funded programs and projects that advance the University's research enterprise. She works with her Board and ASU leadership on a portfolio of institutional level initiatives and the pursuit of new partnerships and resources to advance those initiatives, including support for applied faculty research with defense and intelligence endpoints. She came to ASU from the Lawrence Livermore National Laboratory (LLNL), where she was Director for Economic Development. Dr. Cantwell spearheaded a progressive strategy for LLNL to accelerate innovation and enhance national economic competitiveness. She returned to LLNL in 10/2010 after serving as Deputy Associate Director for Global Security at the Oak Ridge National Laboratory. In her role at ORNL, she provided strategic leadership to develop business with the United States Department of Energy and the National Nuclear Security Administration, the United States Department of Defense, the Defense Threat Reduction Agency, the Center for Radiation Detection, and many others. Prior to joining ORNL, Dr. Cantwell served as the Director for the Threat Reduction Directorate Office of Strategy at the Los Alamos National Laboratory. Dr. Cantwell spent a decade at the Lawrence Livermore National Laboratory, where she helped stand up the Homeland Security organization after 9/11. She spent several years at NASA HQ as a Program Manager for the life and microgravity sciences. Dr. Cantwell is a graduate of the University of Pennsylvania, Wharton School (MBA, 2003); the University of California, Berkeley (PhD, Mechanical Engineering, 1992); and the University of Chicago (BA, Human Behavior 1976). She is a current member of the National Academy of Sciences Division on Engineering and Physical Sciences as well as the Aeronautics and Space Engineering Board, and has served as Chair or Member of a number of National Academies studies pertaining to human space exploration.

Chairman SMITH. Thank you, Dr. Cantwell.

Let me recognize myself for questions and start off by addressing one to all of you all.

And the question is this, and I hope you'll be very specific in your answer, and that is what should we do about the ISS after 2024? Let me set this up and frame the question in a larger way. You've got NASA's budget at $20 billion, about one half of one percent of our federal budget. We spend about $3.5 billion a year on the International Space Station. We cannot have a lunar mission, we cannot continue our exploration into deep space, unless we significantly increase that budget, which we should not presume that we are able to do. Therefore, we have to make some tough decisions. We cannot have it all. Federal funding is not unlimited.

I know the Administration is looking towards on the transition that the United States would be more of a customer than an operator, but if that is still going to cost us upwards of $2 billion, that's not much of a saving. That's not going to get us back to the Moon. It's not going to get us elsewhere. So what do you think we should do about the International Space Station after 2024? And Mr. Gerstenmaier, let's start with you.

Mr. GERSTENMAIER. Okay. I think as we've kind of discussed earlier and you can see in the transition report, we see the need for a continued activity in low-Earth orbit for an extended period of time. I think, as we heard from some of the other witnesses here, that there's a need for a continuous presence to do research. We're not done in low-Earth orbit. It enables what we need to do in deep space. Some of the systems that we're going to be using to go beyond the Earth-Moon system or use in the vicinity of the Moon, those absolutely need to be tested on space station.

Chairman SMITH. Okay. What is our continuing presence in low-Earth orbit going to cost us?

Mr. GERSTENMAIER. Again, I think that's what we need to start really working very hard now to go look at these models that were described earlier. We need to take serious steps forward. I mentioned earlier in my testimony that we're going to do these as commercial companies for studies to come back, show us their business plan, show us their market analysis——

Chairman SMITH. Okay.

Mr. GERSTENMAIER. —show us what we think the cost would be for operations in low-Earth orbit——

Chairman SMITH. Okay.

Mr. GERSTENMAIER. —for NASA's defined need to——

Chairman SMITH. In order to have sufficient funds to, say, go back to the Moon, have a lunar mission, what would be the most we could spend for human presence in low-Earth orbit?

Mr. GERSTENMAIER. Again, I think you could see what we're able to do today with Deep Space Gateway and those activities, we believe we can support where we are today with space station, and those type of Gateway activities heading towards the Moon, and then as the SLS activities ramp down, the commercial crew activities ramp down, those development funds are reduced, we go into production and ops for SLS. That frees up funds that could be used for lunar surface activities and lunar landers.

Chairman SMITH. Okay.

Mr. GERSTENMAIER. So I believe roughly at the budget we have now, with some consideration for inflation and economic growth, we can support a low-Earth orbit program reduced somewhat and also a lunar activity program.

Chairman SMITH. Okay. And, again, you're not willing to put a cost on the low-Earth orbit human presence?

Mr. GERSTENMAIER. I can't give you a specific value.

Chairman SMITH. Okay.

Mr. GERSTENMAIER. I think what we need to do is see what comes from industry——

Chairman SMITH. Okay.

Mr. GERSTENMAIER. —see what's reasonable, and then do the balance—the budget analysis——

Chairman SMITH. Yes, it just—my frustration is it seems to me that we're continuing to think we can do it all but we're not willing to put a cost on anything. That's just the frustration.

Dr. Lal?

Dr. LAL. Chairman Smith, as you said, a presence in low-Earth orbit is not the same as having an ISS, and we absolutely need to do everything we can to see if there's a way for us to be in LEO without, you know, it costing $3–4 billion a year. And so I look—you know, as I said in my testimony, a better analysis of whether privatizing existing parts of the station would be most—more cost-effective versus having free-flyers, commercial stations, and according to our study, the cost—annualized cost of a commercial station would be about $2.25 billion, so that's something to be thinking about.

Chairman SMITH. It's something to be considered, but then that's a saving of only about $1 billion, the difference between roughly $3.5 billion or $3.3 billion now and the $2.25 million or whatever it might be, that doesn't seem to be to me—I mean $1 billion is a lot of money but it's not necessarily going to pay for a lunar mission and a mission into deep space beyond that. So I see that as maybe a distinction without much of a difference where it's still going to cost us over $2 billion. I think the savings have to be significant if you're going to pay for significant other missions. But do you want to respond to that?

Dr. LAL. So, I mean, I was talking about the cost. There's also potential revenues, which could be between $450 million——

Chairman SMITH. Yes.

Dr. LAL. —to $1.2 billion again. You know, we are talking ten years out and predictions are hard——

Chairman SMITH. Yes.

Dr. LAL. —but, you know, the net revenue could be between, you know, negative—a few million to positive $700 million.

Chairman SMITH. Okay. I still wonder that we're putting off the hard decisions, which isn't helpful to us, but I understand your position, so thanks for that.

Dr. Cantwell?

Dr. CANTWELL. I will say that—two points first. The science portion of the budget is minuscule, and the science community is relatively agnostic as to what platform is used to conduct the science. So we have two real challenges. One is, right now, the International Space Station is the only platform to which the U.S. science community has access——

Chairman SMITH. Right.

Dr. CANTWELL. —for long-term studies.

Chairman SMITH. Right.

Dr. CANTWELL. So we would wish to see that there were other options. And the way that they are funded were relatively agnostic about—as long as the science community's overall costs are included in consideration of how those new developments in terms of what I call business model, what's the confluence of our federally funded access——

Chairman SMITH. Okay.

Dr. CANTWELL. —as well as commercial support and other means for having U.S. presence in LEO.

Chairman SMITH. Okay. Thank you. My time is expired. Without objection, I'd like to submit two letters for the record on America's human presence in low-Earth orbit. One is from Dr. Gale Allen, Executive Director of the American Society for Gravitational and Space Research, and the other is from Dr. Mary Lynne Dittmar, a noted expert on spaceflight programs.

[The information appears in Appendix II]

Chairman SMITH. The gentlewoman from Texas, the Ranking Member, Ms. Johnson, is recognized for her questions.

Ms. JOHNSON. Thank you very much, and thanks to all of you for your testimony.

As I mentioned in my opening statement, we now have an International Space Station transition plan that Congress mandated and NASA delivered. While the plan, as it is called, lays out several issues, it raises even more questions that need to be answered.

To start with, the Administration is proposing to end direct U.S. financial support for the space station in 2025. I'd like you to comment on what that means, how much international input you've had, and if sufficient private funding is not forthcoming to compensate for the loss of that government support, does the Administration plan to deorbit the ISS? And will the Administration decide to keep the financial support going, and if so, how much longer? This is not just a U.S. decision or it shouldn't be because it's an international contract.

So I'd like you to—each of you to comment on how far we've gone and including those stakeholders in these—in this design to—for the future of the ISS.

Mr. GERSTENMAIER. The International Space Station program has had numerous discussions with our international partners about the future of ISS and what our plans are beyond 2024 into 2025. We've reached no firm decisions or discussions have not resulted in firm decisions moving forward. They understand what our thinking is and our plans.

If you look in the transition report, in addition to the date and the discussion about ending direct funding in 2025, there's a series of principles that are called out in that transition report, and we think those principles are very important. And the international partner community agrees with those general principles.

So I think we've had a discussion about what we need in low-Earth orbit. I think our international partners agree with us we need some presence in low-Earth orbit. They're also working with us to go build standards and also to move out into deep space. So they see this tension between us needing to stay in low-Earth orbit and willing to move human presence in the solar system, and we are actively engage with them in working those—the items that you discussed.

Ms. JOHNSON. Okay.

Dr. LAL. I guess my only comment to your question would be the last time the space station was extended from—in 2014 from 2020 to 2024, it wasn't clear at all if all the partners were going to join us in extending the station, and it is certainly not clear now if they would be willing to extend, given that they all have plans to partner with us on deep space and lunar exploration plans. And that is something to—that is an important consideration given that, you know, some percent of the O&M budget of the station is paid for by the international partners. So their consideration is very important in this decision going forward.

Dr. CANTWELL. Just one comment. The science community is relatively inherently international and shares science assets on the space station. So the biggest comment I would have, the concern of the community is that if a transition point was selected and held as a matter of course that we experience a gap in capacity to conduct the continuity—science continuity is not available both for funded science in—that trains people, as well as the conduct of experiments.

Ms. JOHNSON. Thank you. What would a private company—what would make the private company interested in picking up a $3 billion annual cost of supplying, operating, and maintaining a part of the U.S. portion of the expense for the space station? Have you had any private companies express that interest?

Mr. GERSTENMAIER. I think we're starting to see onboard space station today interest in private companies in utilizing the unique properties of space for potential revenue-generating activities. There's been—discussed the manufacturing things earlier, and those look like they may have promise. We've seen some pharmaceutical interest, et cetera, so there's some beginning small interest in utilizing space for these companies to generate some revenue.

I think we have to be careful when we think about what we continue in low-Earth orbit after the space station. We can't probably continue a facility as large as the space station. It took us a tremendous amount of time to build the space station. I think we'll end up with much smaller space stations. Transportation costs are critical, as has been discussed in these—by the other members here, so we need to reduce those costs. But I think we get the operating cost down, and there's potential that we could get some cost-sharing in this time frame. Whether they could take the full cost burden, I don't think so, but there could be some initial things that help lower the burden, and even the small savings help us advance what we want to do in deep space.

Ms. JOHNSON. Thank you. My time is expired, but I want—if you'll send me the answer to this question of the private commercial companies who've expressed an interest in taking up the United States' responsibility, if you'll just mail that to me, I'd appreciate it.

Mr. GERSTENMAIER. Okay. We can do that. And we've officially requested that through this NASA research announcement or will be requesting it through a NASA research announcement for studies. We'll provide you a list of all the potential providers to that— or response to that.

Ms. JOHNSON. Thank you.

Chairman SMITH. Thank you, Ms. Johnson.

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

Mr. ROHRABACHER. We're spending $3 billion a year. How much are our partners spending?

Mr. GERSTENMAIER. Probably $1–2 billion collectively across all the partners.

Mr. ROHRABACHER. And could you list those partners for us, please?

Mr. GERSTENMAIER. It would be Canada, Russia, Japan, and then the European Space Agency.

Mr. ROHRABACHER. So the total cost is more like $4.5–5 billion a year rather than $3 billion a year?

Mr. GERSTENMAIER. Yes.

Mr. ROHRABACHER. Right. So after a certain number of years, now we're talking about, what, seven, eight years from now, we have this big chunk of metal up there and something has to be done with it. And there's no way that we can just turn this over to anyone and say, well, that's a $4.5 billion expenditure that you can assume the payments at this point because what's being done can't generate that kind of revenue. Is that correct?

Mr. GERSTENMAIER. Again, today's studies and today's analysis don't show that that revenue can be generated.

Mr. ROHRABACHER. I'm sorry, I didn't hear that.

Mr. GERSTENMAIER. Today's analysis shows that that can't be generated.

Mr. ROHRABACHER. Right.

Mr. GERSTENMAIER. Maybe——

Mr. ROHRABACHER. So we have other things we want to do in space. Are we just simply saying today that this has been—I mean, I was here, I remember, I don't want to brag but I think it was my vote in this Committee that was the pivotal that moved the project forward all those years ago. So we just say, those of us who were here and involved in this project, "well, it was worthwhile, it's run its course, time to leave it behind?" Is that what we're talking about?

Mr. GERSTENMAIER. I mean, this is precisely why the Administration took the position that it did. We think now is the time to start looking at what options are available to us, see what we can get from the private sector, see what they can do, ask them for their ideas. Are there smaller instantiation of space station? Could they use of piece of space station to satisfy their needs and leverage and build an economy in low-Earth orbit? Now is the time to start that planning so in the next seven years we can have an approach and we can understand what the residual cost we still need to carry on our side and what can be carried by the private sector and how it can meet our needs.

So I think the reason we took the position we did in the transition report and set the date of 2025 was essentially to begin a serious discussion to make sure that we are ready to transition low-Earth orbit in some entity to a sustainable thing that meets all the objectives and gives us the benefit out of low-Earth orbit that we absolutely need for deep space, and now is the time to work that. I think we have enough time in front of us. We'll ask the private sector to get creative and innovative and help us figure out what to go do. We know the major drivers and costs in the model and we can turn that over to the private sector and see if they can come up with ways to address some of those cost and reduce them and see where we end up in the next seven years or so.

Mr. ROHRABACHER. Do either of you have a comment on that?

Dr. LAL. I guess I would just like to say that when folks talk about commercial station, they're not talking about something as big as ISS. You know, the commercial stations that we learned about in our study were 1/3 the size of the ISS, more like the Skylab. They were 1/20 the mass of the ISS. And with those kind of platforms, it is feasible to generate adequate revenues that with, you know, some amount of, you know, government payment that they could be commercially viable but not ISS-sized.

Dr. CANTWELL. Very quick comment. In the science community what we've seen over the last six years is what I will characterize as the CASIS experiment, and it has absolutely yielded an increasing level of understanding and knowledge about how some components of the ISS capacity can be attractive to commercial entities.

So I would point to two things. One is it takes a little time, and the other is that we do have the capacity to begin to look at these things from—I won't call them experiments but we can query the commercial sector and get good answers.

Mr. ROHRABACHER. Let me just note that this project has been an interesting project to follow all the way through, as I have. It indicates one thing, that we have learned how to construct big projects in space, which could well serve humankind in the future. And I believe that we have lots of challenges that we need—I've been trying to always remind people that we could see an asteroid heading toward the Earth, and we need to be able to deflect something like that threat. There are things that we will be capable of in the future that we're not capable of now, and it might require us to have these skills that we've developed in a major construction project in space.

So I'm watching and, Mr. Chairman, I want to thank you for your leadership over these years in this project. And I like the answer. The fact is we're looking ahead now and we want to have as many creative ideas as we possibly can to meet this challenge so that this—what's left of the space station's mission is not a waste. But so far, we've learned a lot, and thank you, Mr. Chairman.

Chairman SMITH. Thank you, Mr. Rohrabacher.

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

Mr. BERA. Thank you, Mr. Chairman.

I think there are a couple truths here that I think, Dr. Cantwell talked about one truth, which is from the scientific community they're agnostic other than they need a platform under which to conduct these long-term experiments, whether it's long-term microgravity exposure or radiation exposure. And there ought not to be a gap in that. Again, if we we're articulating longer-term multi-decadal, you know, goals in mind.

So as part of this conversation, ISS, no ISS, I think we have to say, okay, what is that replacement that allows us to continue from a scientific research and discovery perspective these longer-term studies.

I also, just another truth, and I think as we're having this conversation, I don't disagree with the Chairman that resources are limited and we're talking about federal funding versus commercial versus international support in an isolated conversation, ISS, but I think we ought to talk about it in terms of the entire conversation about space because today, when we talk about our return to a lunar mission, it's different than it was in the days of Apollo where NASA was the launch vehicle, was the landing vehicle, was the science component. You know, today, you have multiple launch vehicles that potentially fill that piece of the lunar mission.

You—you know, my—I suspect that we will have commercial landing vehicles as well, so, you know, in that context—and you will likely have international launch vehicles and landing vehicles as well, so how do we not just have the budget conversation in isolation around ISS but also look at, you know, are there ways to defray costs on the—you know, NASA by itself doesn't just have to do the lunar mission. There will be commercial and international entities in that conversation as well. And I think those are incredibly important.

And I also think another component that we should not lose sight of is, I'm told that, thus far we've spent $87 billion in assembly, in development and operations of the ISS. Those are sunk costs that the taxpayers have already invested. We should not be shortsighted to say those are not costs that you're going to recover. If we've already spent those sunk costs, we ought to think about that in the context of our return on investment as well because, again, you don't have to replicate that $87 million in assembly and that should be a component here.

Am I thinking about this correctly, Mr. Gerstenmaier? And then I'd be curious about, you know——

Mr. GERSTENMAIER. Yes, I think you bring up some very, very good points. And I think we also sometimes think of this as a lunar activity or a low-Earth orbit activity. I think we ought to think of it more as a combined activity. So when I talked about standards, if we can now build components that will operate on station that will be used in a lunar system, so the life-support systems that the crews—the next generation of life-support systems used on the International Space Station, those will be identical systems used in the lunar station. So there is not a one-for-one duplication in the costs associated with lunar and low-Earth orbit. There are effectively one system used in both places.

So I think if we think about this in a broader sense, we can look for a sustainable plan that allows us to operate and look at the total budget that we have for NASA and look at it as an activity that we have to do both the lunar program and a low-Earth orbit program, don't look at them as separate activities, and see if we can figure out a creative way to utilize those together to achieve our end goal.

Mr. BERA. Great. Dr. Cantwell, do you want to add?

Dr. CANTWELL. I would only add one really general comment and back it up with a little bit of fact, which is that we are, as a country, absolutely capable of innovating our way through this. We've seen it happen in the past. It is an incredibly challenging problem, but I do think that we can do that.

Now, I would back that up with a little bit of a geeky discussion about 3–D printing in space, which we are seeing a manufacturing revolution, and that revolution is associated, quite honestly, with the full digitization of manufacturing. The implications of that for planetary missions are quite astounding, and we have only really intellectually touched that. While we've done a little bit of manufacturing in space, intellectually, the implications of that are really amazing. We have many examples of that kind of thing.

Mr. BERA. Well, so let's—as we in Congress have those conversation in concert with NASA and others, let's make sure we're open to our imagination and we're looking at the full scope of this and that it's not just $3 billion a year of funding until 2024 and then we shut the lights off but it could even be a transition where, you know, in 2020 it's $2 billion and there's other sources of revenue coming in. So we shouldn't see it as either/or we should look at it in the entire context as technology improves.

So I'll yield back. Thanks, Mr. Chairman.

Chairman SMITH. Thank you, Mr. Bera.

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

Mr. BROOKS. Thank you, Mr. Chairman.

NASA's first commercial resupply services contract, or CRS–1, awarded International Space Station cargo resupply contracts to SpaceX and Orbital Sciences, now Orbital ATK. At the time of the award, both were using expendable or one-time use launch vehicles.

Commercial Resupply Services contract number two (CRS–2) awards were announced in 2016, with Orbital ATK, SpaceX, and Sierra Nevada receiving contracts. A recent audit by the NASA Office of Inspector General found that, quote, "Overall, CRS–2 costs are still projected to be roughly $350 million higher than CRS–1," end quote.

With regards to each contractor, the audit notes, quote, "When compared to the cost of each contractor's final CRS–1 mission, SpaceX's average pricing per kilogram will increase approximately 50 percent under CRS–2, while Orbital ATK's average cost per kilogram pricing will decrease by roughly 15 percent," end quote. SpaceX appears to be using reusable launch vehicles for CRS–2.

In your opinions, why have expected costs for SpaceX's reusable launch vehicles gone up so much when reusability was supposed to save the government money?

Mr. GERSTENMAIER. Again, I think what you're seeing here is kind of market forces at work. When the original CRS–1 contracts were bid, I'm not sure the contractors really knew what it cost to launch cargo to space. In fact, there were no rockets available to do that task. So they gave us a proposal. We accepted that proposal, and they delivered on that proposal. Then, in the second round they have a better understanding of what those costs are, and we see some of those costs are coming back.

From a government standpoint, we look at that, we look at price reasonableness. We got good value and good reasonableness. I think what it shows us is there's a strong tool on the government side, and that's competition. If we can set ourselves up in the future for future contracts and other activities where there's good competition, then that allows us to put some pressure on the commercial sector and the private sector to lower costs and still give us the services we need moving forward.

So I think we're learning through this process of how to interact and how to contract and get our activities in place. I don't see these changes as a big deal. These are just natural progressions and changes that will occur through contracting, but we on the government side can use that to our advantage as we think about how we're going to get next generation of modules, next generation of systems used in space.

Mr. BROOKS. Mr. Gerstenmaier, if I understood you correctly then, it's your belief that the price increases for SpaceX were more market force-driven as opposed to the use of reusable launch vehicles versus one-time use launch vehicles?

Mr. GERSTENMAIER. That's my opinion, yes.

Mr. BROOKS. Dr. Cantwell, based on your interactions with industry, how do you foresee the odds of a commercially viable human presence in low-Earth orbit absent any government support doing?

Dr. CANTWELL. Caveat, the science community would be the place where you would not seek expert opinion on the commercial approach. We have, on the committees that I've served, queried mostly new space companies over the last three or four years, seeing this transition coming. And what we find—I will just say that what we find is a unique willingness to work with the science community to find ways as we progress and innovate these new business models to accommodate science. That has certainly not come to any clear conclusions at this point, but we do find that particularly American companies are more than interested in supporting American science.

Mr. BROOKS. Mr. Gerstenmaier, as I understand it, the inclination of the International Space Station limits its use for staging, assembly, or logistics for further human deep space exploration. Would a future human presence in low-Earth orbit, in a different orbit create new useful options for an American human presence in low-Earth orbit or is there no relationship regardless of the inclination?

Mr. GERSTENMAIER. The inclination directly affects the amount of mass you can take to orbit, but once you overcome that, the ability to go from a 51.6 degree inclination to the Moon and other activities or 28.5 is not that radically different going from those orbits outward, but there is a small impact of the launch mass impact going to the higher inclination orbit. So I don't see inclination as a big driver. It takes away some of your performance for the initial launch, but in the big scheme of things, either inclination can be workable. We've been able to work very well in the 51.6 degree inclination.

Mr. BROOKS. Thank you, Mr. Gerstenmaier and Dr. Cantwell.

And, Mr. Chairman, I yield back.

Mr. BABIN. [Presiding] Thank you for those questions.

Now, I recognize the gentlewoman from Hawaii, Ms. Hanabusa.

Ms. HANABUSA. Thank you, Mr. Chairman.

Dr. Cantwell, in reading your testimony, I was struck by certain things, and let me explain. You seem to have a concern about how we're going to start the transition. You even used references to research and how we go from where we are now, basically LEO-type of situation, into deep space. In particular, what I was struck by is it looked like the whole space station issue started like in the mid-1980s, and it—there's negotiations going on and you finally have human inhabitants by the year 2000. And you seem to say in your testimony that, right now, we are finally now—I think are the exact words that you used—in a fully functioning laboratory with a well-trained crew that understands the conduct of science.

So my concern is, as we transition from what we have now to a deep space kind of exploration, how long do you think we're going to get—to get them? How long will take for us to get there from what you seem to have a great concern about if I'm reading you correctly?

Dr. CANTWELL. So I always characterize my remarks not so much as concern but as pointing to those capacities that are necessary for science to be conducted and the general flag-waving that says please don't forget that the science community needs certain things. It is a small piece of the budget but needs certain things in order to do the work that would allow us to, for instance, successfully go back to the Moon and on to Mars.

So I will perhaps restate something I said a little bit earlier, which is that the major concern or pointer is that the International Space Station today—which in my remarks meant a fully functioning—that it is meeting all of the science requirements it was established to do at this point, and that is a relatively recent fact. All of the science assets have been brought up and in place, and the science that was—has been thought about for many years can be conducted. Now—and this is true in—just really in the last—the last asset was probably—Mr. Gerstenmaier can help better than I—but in the last couple of years.

So we have an asset that can now do the long-duration studies. Those are the studies that will underpin and support our capacity to spend more than the amounts of time that we have had astronauts on the station, as well as to have equipment, engineered systems that can function for long periods of time without resupply, and that is as relevant to lunar surface operations over long durations, and then the studies that we will need to do to go further out.

Just as a point of reference, we could imagine doing long-term studies in a lunar Gateway type of platform, but it would cost us a lot more to get those studies out there and bring them back for reinvestigation.

Ms. HANABUSA. One of these statements you made—I think this was in response to Congressman Bera's questioning—you said that basically you have faith, as a country, we can innovate our way through all of this. I think it was—those were your exact words. And I guess what I'm reading in all the testimonies, especially in yours, is that, you know, it's—as a country, we no longer seem to be talking about space in terms of the United States or Russia or any one country. We seem to have gone past that, and we are talking about science in a global or international way, whichever you want to talk about it. And this whole space exploration is also taking on that kind of, I guess, cooperation in order for us to succeed. It seems to be inherent in how we have evolved.

Now, in light of that—and you may not be—I'm pretty sure you're going to respond to me that scientists are not the ones to respond to this, but given that, how is it that, given the temperature of our relationships—because this is based on how countries are getting along—how do you see that affecting the conclusion that you seem to arrive at, which is that we can innovate our way through all of this?

Dr. CANTWELL. So let me start with the conclusion because I have been party over my career—now a pretty long career—to innovation through difficult federal pricing challenges all the way to—I now work at a—what by any stretch would be characterized as an incredibly innovative university with regard to the conduct of higher education, another grand challenge for the United States.

But the fact is that innovation is a mindset as much as anything else. We have the intellectual capacity in the United States, and we have—frankly, we have the dollars in the United States. It is a mindset. So I will say what you expected me to say. But I think the reason that the science community is so international and global is that the science community is driven by the marketplace of ideas. We—you know, by curiosity, by discovery, and by the delivery of that curiosity and those discovery principles into things that matter. Typically, those really aren't defined by national boundaries.

Ms. HANABUSA. Thank you. My time is up, so thank you, Mr. Chairman.

Mr. BABIN. Thank you. And I'll recognize the gentleman from Texas, Mr. Weber.

Mr. WEBER. Thank you, Mr. Chairman.

Dr. Lal—well, let me do it this way first—Mr. Gerstenmaier, am I saying that right? In your discussion with Congressman Rohrabacher, you made the statement we absolutely need the benefit of low-Earth orbit for deep space. Why is that?

Mr. GERSTENMAIER. Again, you've kind of heard it from some of the other panel members, but it's very difficult to do research and new development around the Moon. Just the transportation costs of getting there are much, much higher than they are in low-Earth orbit. The cost of doing that activity is much more difficult. Doing that development activity in low-Earth orbit is exactly the right place to do that, and then you can take that, and after it's developed, then extend it to the lunar——

Mr. WEBER. Right. Okay. So you're at—I got that. Do you know the ISS, what its footprint or its cubic feet is or how big it is?

Mr. GERSTENMAIER. It's roughly the size of a five-bedroom house, internal dimensions of—lengthwise, it's about the size of a football field.

Mr. WEBER. Weight?

Mr. GERSTENMAIER. Nine hundred thousand pounds.

Mr. WEBER. Longevity? How long does it last in space?

Mr. GERSTENMAIER. We have studies that shows that it can last structurally till 2028 and probably be extended beyond 2028.

Mr. WEBER. Will it fall to Earth eventually?

Mr. GERSTENMAIER. If we don't re-boost it. Our plan is to either deconstruct it, bring it apart in pieces, use those pieces for some other application, or deorbit it essentially as a large piece safely into the ocean.

Mr. WEBER. Well, if you deorbit it into the ocean, does most of it burn up?

Mr. GERSTENMAIER. Yes, the majority of it would burn up. Some small pieces would probably make the surface.

Mr. WEBER. Majority—you can keep your mic on for a minute.

Mr. GERSTENMAIER. All right, sir.

Mr. WEBER. Majority being—when you say majority would burn up—60, 70, 80 percent?

Mr. GERSTENMAIER. Probably 90 percent or so, maybe even 95 percent. There are several large structural components. There are some large structural titanium pieces and some large aluminum structure that probably would make the surface of the Earth based on our models.

Mr. WEBER. But we would still maintain the capability of steering that for lack of a better term into where we wanted it to go?

Mr. GERSTENMAIER. Yes, we would steer that such that the footprint would be over the Pacific Ocean, and it actually stretches multiple miles. We actually look at a descent profile that would stretch a couple hundred miles across the ocean of where the debris potentially could land. We've actually investigated that with some of our cargo vehicles. When they return, they also are destructively burned up. We have purposely lowered the angle of attack of which those vehicles come into the atmosphere to make them shallower, similar to what the station would be so we'll actually know what that quantified footprint is so we can enssure that when station is destructively reentered, it can not impact any human inhabitants on the Earth.

Mr. WEBER. Okay. And Dr.—you can turn your mic off now.

Dr. Lal, would you say your report essentially ruled out the idea of a commercial space station and that we should definitely pursue privatization?

Dr. LAL. Our report ruled out a fully commercially viable station as in without any government subsidies, the commercial sector will not make any money.

Mr. WEBER. Is it based on the space station he just described?

Dr. LAL. Absolutely not. The station that we—that was part of our model is about 1/3 the size, 330 cubic meters rather than 930 cubic meters.

Mr. WEBER. It's smaller?

Dr. LAL. A third the size, and it's also 1/20 the mass. As I said earlier, commercial stations—I mean, you know, space station's, Battlestar Galactica. We—commercial parties may not need that.

Mr. WEBER. Okay. Okay. Let me go to Dr. Cantwell. Do you think that the difference in operations among different low-Earth orbit use cases suggests that a few smaller purposed-built private facilities may—a few, more than one—may succeed where a larger general-purpose platform is not viable on a purely commercial basis?

Dr. CANTWELL. I'll attempt to answer that more as an engineer if you will go with that.

Mr. WEBER. Sure.

Dr. CANTWELL. There are operational requirements which could be met by a small number or even a large number of alternative platforms. The challenge is the cost of the people who are conducting those experiments on orbit, the launch cost, cost to get the scientific material up there and back, so we've recommended sort of a full-cost assessment of the needed science for this very reason. You can then look at can it be conducted in what are established as a series of platforms.

Mr. WEBER. Okay. I'm getting really low on time, but let me just—so if you had one in a certain orbit—I don't know how many miles that would be—if you expanded the next one above it to 10 miles, 20 miles further out, would there be benefits obviously in having three different layers, for example, of orbits?

Dr. CANTWELL. There could be for certain science. I would say that, again, the massive driver for all of this from a science perspective for human exploration missions is the duration of time in microgravity that studies can be conducted and the radiation environment so there would be a difference if you went high enough in the radiation environment.

Mr. WEBER. Are you able to quantify that, the difference in radiation and the different——

Dr. CANTWELL. I don't know that we've actually looked at it specifically from that perspective, but the mid-decadal study does characterize the radiation studies that are needed.

Mr. WEBER. Okay. Thank you, Mr. Chairman. I yield back.

Mr. BABIN. Yes, sir. Thank you.

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

Mr. CRIST. Thank you, Mr. Chairman.

Mr. BABIN. Certainly.

Mr. CRIST. And thanks to our witnesses for being here today.

I was Governor of Florida in the years leading up to the retirement of the Space Shuttle. I remember the apprehension with which many throughout our State viewed the end of that program. As it turns out, that apprehension was in fact warranted. Not only did the loss of the shuttle depress Florida's economy but it hurt the families who worked on the shuttle, as well as those who worked in industries supported by the program like tourism.

Thankfully, Florida's blessed with the talent to innovate in challenging circumstances, and now, we have a thriving commercial space industry to fill that void. However, much like the shuttle, I'm sure there will be job losses or realignments as a result of the decommissioning of the space station.

Mr. Gerstenmaier, what is NASA's plan for those workers and their families who will be affected by the transition? Will there be a workforce transition plan for them? And if so, when can we expect to see one?

Mr. GERSTENMAIER. Again, I think as we've discussed in our transition report, we have some principles laid out for what the physical facility would be in space. Then I think after we understand kind of what the concept is we want in space, then we need to start working on the terrestrial plans to provide for what you describe, to make sure we've got a good transition where they may be government jobs today, they may be private sector jobs today, much as you've seen in Florida, that transition occurred. I think we could do a better and smoother job of that on the ground. And so we can plan for that.

Same thing as we move into deep space. Some of the detailed engineering, some of the hard sciences, there's going to be a new demand for new students and new engineers in those areas, and we can start bringing those online. So we need to do a phased-in transition and don't do just a stop and then wait and then figure out what the plan is moving forward. So we will do that next step of transition planning after we lay out—after I believe we lay out kind of our general concept of how we want to do exploration.

Mr. CRIST. Thank you, sir. My next question is directed to all the witnesses. Do you think there will be enough demand to support commercial activity in low-Earth orbit following the end of space station operations? What are the barriers to generating that demand? And what do you envision will be the primary driver of such a market?

Mr. GERSTENMAIER. I can answer a piece of it. From the NASA perspective, I think we have an understanding of what activities we'd like to continue to do in low-Earth orbit even beyond the station. So we need a place to train crews, to give them experience of operating in space. As Dr. Cantwell talked about, I think we need a station to do some research that's done close to Earth that can get there with low transportation costs. That augments what research we could be doing in a Gateway-type of activity around the Moon.

So I think we understand the NASA demand. What we need to do is see if the private sector can, on their own, determine some demand that they want to have for research activities in space or from operations in space that they could get benefit from. Then that total combined demand, both government and private sector, makes up the plans moving forward. Now, we're going to ask in some studies for exactly that market analysis from companies.

Dr. LAL. So in our study, the 21 activities we looked at, there were three that stood out as having, you know, solid demand behind them. One is optical fiber, exotic fiber, a second one is satellite assembly, and a third one is sovereign astronauts and private astronauts, so three that stood out in terms of demand. And with respect to the barriers, launch cost is the biggest barrier to a commercially viable space station.

Dr. CANTWELL. The only thing I would add is that if we have, as I believe we should, a continuing research presence in LEO, then we will—this is not probably within the next decade, but research tends to pull out new applications that commercial companies are very interested in. And the place that I would really point to for the likelihood of that is in materials science.

Mr. CRIST. Mr. Gerstenmaier, the transition report speaks to the importance of the space station and low-Earth orbit to both research entities and the commercial space launch industry. Would you please describe NASA's commitment to ensuring there will not be any gap or reduction in continuous crew and cargo access to the low-Earth orbit, regardless of platform?

Mr. GERSTENMAIER. Again, what we're looking at is we described—there's a budget laid out, a commercialization budget that starts at $150 million in 2019. That's laid out to try to see what is needed from the private sector in terms of another facility other than station or do they want to use space station or do they would use some combination of space station and another facility. To service those entities, we're going to need a commercial launch capability.

As we talked about activities around the Moon, we don't need to go look at cargo again from a government-only program. We can go immediately to cargo for lunar activities at Gateway using commercial providers, so there's a natural meshing between what we've done in low-Earth orbit and what can be done around the Moon. They can take dramatically less cargo to the Moon, but it still—with the rockets they have today, they can get cargo that can be substantial for us and needed around the Moon. So I think we will take that transportation market we've established and figure out creative ways to use it both from low-Earth orbit and also for our deep space activities.

Mr. CRIST. All right. Thank you, Mr. Chairman. I yield back.

Mr. BABIN. Thank you very much.

And I'm going to yield myself here five minutes for questions.

The first one is to you, Mr. Gerstenmaier. There are approximately 1,370 civil servants and 4,725 reportable contractors supporting the ISS program in fiscal year 2018. Many are located in my district, at Johnson Space Center in Houston. Yesterday, you were asked in the Senate testimony how mission control at Johnson Space Center would be impacted by an ISS transition. You stated that NASA's intent is for mission control being conducted at Johnson Space Center for all future HEO programs and that there would be no major impact. I would like to ask you to elaborate on that for us as well in this hearing.

Mr. GERSTENMAIER. What I was alluding to as we talk about the Gateway activity around the Moon, that vehicle that will be around the Moon that can be in multiple different orbits around the Moon, it's not like a space station. It can be in different orbits. That will be commanded and operated from the Johnson Space Center through the mission control teams.

Just as the Johnson Space Center played a critical role in understanding how we do rendezvous and proximity operations in low-Earth orbit, they set all the operating procedures for how that would be developed, how we routinely keep crews healthy in low-Earth orbit and those activities. All those things will carry into deep space so that fundamental research and analysis that needs to be done on how you use the gravity of the Earth and the Moon and the sun to maneuver and manipulate around to save propellant, all that will be done by the scientists and researchers at the Johnson Space Center. So that first—that pioneering of how we get comfortable with keeping humans in deep space, how we learn to essentially maneuver and manipulate across the gravity rivers in space to other deep space locations, all that will be done by the teams at the Johnson Space Center.

Mr. BABIN. Thank you very much.

I think, Dr. Lal, first for you, NASA benefits from commercial partnerships and can help with a lot of early technical development, but are the medium- to late-stage economic development of space the responsibility of NASA, another part of the government, or not a government responsibility at all?

Dr. LAL. That's a good question. It depends on the particular area. In the context of the space station, I think there's enough experience that this is a transition that can begin to happen. There are, you know, companies that have—you know, whose leadership has been part of NASA. NASA has learned lessons from the station. NASA is willing to offer expertise through space act agreements and other ways, so this would be an area where there's potentially less—little enough R&D that it could be outside of the government.

And of course we're talking about operating a platform. There's also the launch service where we've seen that commercial sector can do a pretty good job. And on the user base, again, NASA is working on developing R&D—users of R&D in commercial areas or even universities where things can move forward without government support.

Mr. BABIN. Okay. Thank you. And then should the—and this is for all of you. Should the United States commit to maintaining a human presence—commit to it, whether public, private, whether permanent or periodic—in low-Earth orbit? Mr. Gerstenmaier, you first.

Mr. GERSTENMAIER. I think there is—

Mr. BABIN. Yes or no?

Mr. GERSTENMAIER. I think there's a need for us to stay in low-Earth orbit as we go beyond low-Earth orbit. So, again, I think as you described fairly clearly at the beginning, it's not an either/or situation. I think we need to do both and we need to figure out a way to accomplish both.

Mr. BABIN. Okay. Well, let me follow up with you while you've got the mic. If the United States doesn't maintain a presence in light of Chinese plans for a LEO space station as early as 2022, are we ceding U.S. leadership?

Mr. GERSTENMAIER. Again, I think we can still maintain leadership into deep space activities. There would be some potential damage if we relied on another entity for operations in low-Earth orbit.

Mr. BABIN. Okay. And then, I'll tell you what, I'll go to Dr. Cantwell next and then if I have time, Dr. Lal. Should the United States commit to maintaining a human presence, whether public, private, permanent, or periodic in low-Earth orbit? Dr. Cantwell very quickly?

Dr. CANTWELL. I think the opinion of my community and my personal opinion is yes, and the reason is that it is the most accessible location with which to do research of interest, and it is the least expensive.

Mr. BABIN. Okay.

Dr. CANTWELL. So we can do—we can get answers to our questions and discover new things faster—

Mr. BABIN. All right. Thank you.

Dr. CANTWELL. —if we have LEO presence.

Mr. BABIN. Thank you. Dr. Lal?

Dr. LAL. Robert Heinlein said, "low-Earth orbit is halfway to anywhere." I agree with him. We absolutely need to have low-Earth orbit presence. It doesn't have to be government-led. We need it for R&D on Earth, we need it for R&D for the future, and we need it to be as the Gateway to the rest of the solar system.

Mr. BABIN. Okay. Thank you. Thank you very much. And that exhausts my time, so the gentlewoman from Connecticut, Ms. Esty.

Ms. ESTY. Thank you very much, and I want to thank the Committee for holding this important hearing.

I hail from Connecticut, and we actually do in my State provide life support services for ISS. We have a long-time commitment around space.

Research aboard the International Space Station is critical to our journey to Mars, and an important aspect of that research will help us develop countermeasures, the harsh environments astronauts will be facing during long periods of spaceflight.

And earlier last year, I met with Captain Mark Kelly and discussed with him the important research with his twin brother and the effects that we're beginning to understand about even a relatively short—compared to what we're talking about for a Mars mission—experience and exposure to microgravity.

In Connecticut, the NASA Connecticut Space Grant Consortium has a awarded a grant to undergraduate students in our State to carry out a project called the Effect of Microgravity on Nanoparticle-Cellular Interaction, which aims to research the effects of microgravity on human health. And this project will use an imaging procedure to look at nanoparticles and their interaction with proteins in human cells and freeze them for—in time to then capture images and assess them later.

Now, a lot of us are concerned about what's happening about the wind down of ISS, and really, Mr. Gerstenmaier, for you first, will the essential ISS research and development needed to enable deep space human space exploration have been accomplished by 2025? And is NASA equipped to stay on track to complete a checklist of countermeasures on microgravity in that time period?

Mr. GERSTENMAIER. Our current timelines show that we can complete the majority of activities by 2025. There's not much margin in activities. And then also I think there could—potentially is a need for some continued research for long-duration periods even beyond the 2025 time frame.

Ms. ESTY. Do you have thoughts of how we're going to achieve that? Because once we don't have ISS, we don't have any good mechanism for studying that.

Mr. GERSTENMAIER. Again, as I think we've discussed at this hearing, we look for commercial platforms that can be an avenue to go take a look in those investigations. And we also have a need to understand some things needed to go beyond the Earth-Moon system, so the Gateway that we talk about, another facility around the Moon, we think that also has application now to look at some animal models for the radiation environment around the Moon, et cetera, that will help us understand what the environment is and countermeasures for that period. So I think we have a continued need for research activities in space.

Ms. ESTY. Well, I think it's going to be very important for Congress and this Committee to be kept apprised of that timetable, and that's part of our concern frankly when we had the NASA reauthorization without having even reviewed the report about how that transition is going to go from the end of ISS.

A number of us are part of the newly formed Planetary Caucus in Congress, and we met last week and interacted with stakeholders and experienced groups. And one of the issues they raised was the important and often under-attended-to aspect of cooperation between nations that's occurred because of ISS, something that there is absolutely no—as far as I can tell—any indication that that is likely to happen as part of commercial endeavors. Would any of you care to talk about that as we are one sole planet—as somebody mentioned last week, we have no planet B.

So part of the value of ISS it seems to me has been the importance of having scientists working across countries, which are not always friendly on all other terms, but maintaining that level of human space exploration, human exploration. And if any of you would care to comment on that because that's one of those pieces, again, not clearly in the jurisdiction of this committee but clearly in the importance and interest of the American people and this government and part of the planning frankly.

If we're winding down ISS, how are we going to be dealing with intercountry cooperation on this incredibly important human endeavor?

Mr. GERSTENMAIER. Again, I think the space station has shown us that we can work together as an international community despite government challenges between us. And I think the challenge of human spaceflight, the challenge of putting humans in space and keeping them alive and keeping them safe draws us together and allows us to work together as a community that probably can't be accomplished in any other way.

And the ISS partnership is tremendously strong. It has built international standards for new hardware and new equipment, which will allow any country, no matter how small they are, to build new hardware for deep space activities.

We've also worked with the international community for the Orion service module. That's the system that propels the Orion in deep space that's being built by the European Space Agency. So we put them in a critical path for our human activities. So you're already seeing a start to carry forward on the ISS experience into deep space.

And I think, as was discussed earlier here in this hearing, that any future activities in deep space will be an international activity, and that's only because station has shown that that's a viable way of cooperating and working together.

Ms. ESTY. I do think the concern, though, is if we don't have something in the interim, ISS drops out, we don't yet have the longer-term projects, and then we're left in the interim with commercial space, individual countries moving forward, and I think that's an under-attended-to issue.

I know my time is expired, but that's something we haven't really been talking about and was really present with longtime partners last week saying this doesn't get discussed enough about the importance for the standards but frankly for this being a human endeavor that we engage in together.

Thank you very much, and I appreciate the Chairman's indulgence.

Mr. BABIN. Thank you. I now call on the gentleman from Louisiana, Mr. Higgins.

Mr. HIGGINS. Thank you, Mr. Chairman. And, panel members, thank you for appearing before us today.

The human presence in low-Earth orbit is crucial as we advance exploration to the Moon and beyond. And I'm concerned about the way monies are invested in low-Earth orbit research. My research indicates that roughly 60 percent of the total operating cost for the International Space Station is transportation to and from the station. Dr. Cantwell, is that true?

Dr. CANTWELL. I think I might—I am probably not the best person to ask about transportation costs, but I believe Dr. Lal has actually looked at this in her study.

Dr. LAL. So, I mean, today, NASA—the ISS budget, I think $1 billion is operations and management and $1.7 billion is transportation, crew and cargo, so, yes, sounds about right.

Mr. HIGGINS. All right. So the need for research is crucial as we look to the future for human presence in space, lunar orbit, lunar surface, Mars exploration, et cetera. And a great deal of this research can be conducted for those missions to be successful in low-Earth orbit, and our goal as this body and this Committee is to encourage the dollars to be invested in actual research. What can we do to decrease the expense of transportation to and from the research which absorbs so much of these dollars?

NASA is not currently confident that private-sector capabilities have matured enough to satisfy NASA's needs and requirements for low-Earth orbit operations. Is that true, Dr. Cantwell?

Dr. CANTWELL. Again, this is what we heard from Mr. Gerstenmaier a little bit earlier today. I would say this is the concern of the science community, and it is not a concern in the sense that our hair is on fire. It is a concern that, as we look at the multiplicity of options for reducing the costs to the U.S. Government of launch and carrying things to and from whatever LEO objects we have, that the science community is part and parcel of those considerations.

Mr. HIGGINS. So what steps should NASA and private industry take to reduce these costs to ensure the efficient commercial use of the ISS or whatever next-generation low-Earth orbit government-funded program in the post-ISS era? What steps can we take that we're not doing right now? Anyone?

Mr. GERSTENMAIER. Again, I think we're pursuing these steps as fast as we can. We're working right now with commercial crew, right? Probably within one year we'll have two providers being able to carry crew to low-Earth orbit. As we think to the future beyond low-Earth orbit, we think transportation is clearly a key driver, so we want to make sure there's not unique systems, that the systems used for low-Earth orbit can be basically the same systems used for deep space.

We also think that the past model where we have lots of disposable hardware that we use, for example, in the Apollo program if we can use the Gateway where it now enables—t here's a piece of infrastructure that allows reusability in space. We might be able to actually even use some upper stages from the rockets as part of the components used to build facilities in space. If we start looking for creative ways where we—

Mr. HIGGINS. Excellent. That's creative thought.

Mr. GERSTENMAIER. —utilize pieces—

Mr. HIGGINS. That's what the Committee——

Mr. GERSTENMAIER. —we can lower some costs.

Mr. HIGGINS. —was hoping to hear.

Dr. Gerstenmaier, by 2024, regarding the ISS, several components of the ISS will be nearly 26 years old, twice as long as its expected lifespan. Should NASA and other U.S. commercial entities remain on the current ISS under a modified program? What safety concerns do you have regarding the aging components of the ISS, and what measures should be taken by either NASA or private industry to ensure continued safe operation?

Mr. GERSTENMAIER. Yes, we continually monitor all these systems on board space station, and we routinely change them out as time is needed. We've upgraded all the computer systems on board space station. As recently as yesterday, we did a spacewalk, and what we did with that spacewalk is we located some pump packages in a region where they can now be changed by robotic activities on station. So if one of these pump systems goes down or breaks, we don't have to do an emergency spacewalk with crews. These are now positioned in a location where we can replace that pump that failed robotically from the ground and restore full functionality of the station.

So the teams are continually looking forward to figure out ways that they can lower the risk, understanding the components may break and they may fail. We'll have replacement components on board. We'll have staffing or spares available to go replace those components as needed and upgrade as needed.

Mr. HIGGINS. Thank you for your very thorough answer.

Mr. Chairman, my time is expired. I yield.

Mr. BABIN. Yes, sir. Thank you. And this concludes our hearing today. I want to thank each and every one of you excellent witnesses. We really appreciate it, and the great questions from our Members up here.

The record will remain open for two weeks for additional written comments and written questions from Members.

So with that, this hearing is adjourned.

[Whereupon, at 11:42 a.m., the Committee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Mr. William Gerstenmaier

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"America's Human Presence in Low-Earth Orbit"

Mr. William Gerstenmaier, Associate Administrator, Human Exploration and Operations Mission Directorate, NASA

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

1. Does the Administration intent to have a commercial operator run the International Space Station or a portion of it, and if so, does that mean the U.S. government would still have the overall responsibility for the facility?

   a. Or does the Administration intend to leave the ISS and use a commercial orbital platform, even if the commercial market demand would not cover the cost of operating a private space station? If so, does the Administration intend to subsidize a commercial space station, and at what level? What would that mean for our International Space Station partners?

   Answer: The eventual future of the International Space Station (ISS), whether it is transitioning the operations of the ISS platform to private industry through the use of public-private partnerships, augmenting it with privately developed modules, combining portions of the ISS with a new private platform, or beginning anew with a free-flying platform and de-orbiting the ISS, will be evaluated using the ISS Transition Principles noted in the ISS Transition Plan, available at the following link:
   https://www.nasa.gov/sites/default/files/atoms/files/iss_transition_report_180330.pdf

   NASA will continue to have a need in low-Earth orbit (LEO) for regular crewed operations, exploration-related human health and performance research, long-term technology development and demonstrations, and Earth, space life and physical sciences research. Access to an orbital platform on which to conduct these activities will be key as NASA and its commercial and international partners prepare for crewed missions to the Moon and beyond. In the private space station model, NASA would purchase services to fulfill these needs as one of many customers.

   NASA will maintain leadership and governing responsibilities for the ISS as outlined in the Partnership agreements, and continue to maintain the essential elements of human spaceflight such as astronaut safety and the high-risk exploration systems. Consistent with the ISS Transition Report and Principles, NASA will continue discussions with the ISS International Partners as they determine their long-term future in LEO. NASA is committed to a permanent presence in LEO.

b. Please send a list of the private commercial companies who've expressed an interest in taking on the United States' responsibility for operating the International Space Station.

Answer: At this point in the process, while the Agency considers a range of options for ISS transition, it is premature to tally the entities expressing interest in operating the ISS. Respondents to the May 17, 2018 NASA Research Announcement (NRA) have submitted study proposals. NASA anticipates multiple awards based on the evaluation criteria. The overall number of awards will be dependent upon the quality and innovativeness of proposed studies, funding availability, and evaluation results. NASA reserves the right to select all, some, or none of the proposals received in response to this Announcement.

2. The recently released Midterm Assessment of NASA's Implementation of the Decadal Survey on Life and Physical Sciences Research by the National Academies stated that, "*All too often, space life and physical science waits in a queue for crew time. Some experiments that are highly important to the decadal survey portfolio need crew time beyond their program allocation and, therefore, never make it to the queue or may be dropped.*" How does the Academies' finding on a shortage of crew time for research comport with the ISS Transition Plan's proposal to make ISS resources, including crew time, available to commercial companies as part of a commercial use policy?

Answer: Consistent with the ISS Transition Principles, NASA's exploration strategy and the U.S. Government's obligation under the International Partner agreements, NASA has developed long-term LEO requirements that are meant to be part of a broader commercial market in LEO where NASA is one of many customers. One such requirement is: "*Space Life and Physical Sciences Basic and Applied Research at Current Levels and Capabilities.*" NASA will continue to require access to a LEO platform to enable exploration and to pioneer scientific discovery for and with other Government agencies, commercial companies, and international partners. NASA will continue to focus research in the highest value areas as guided by the National Academy of Sciences' (NAS) Decadal Survey and NASA exploration program needs. These areas include research in plant and microbial biology, animal and human biology, fundamental physics research, cryogenics and heat transfer, combustion research, and applied materials research, among other.

As part of a commercial-use policy for the ISS, limited resources such as crew time would be prioritized to those activities predicted to have the highest value and impact.

a. Does NASA believe that excess crew time will be available after crew time requirements for decadal survey research experiments are satisfied? If so, on what basis?

Answer: Crew time devoted to NASA research activities on ISS and its successor(s) will continue to represent a balance among NASA's requirements, including those articulated in the NAS Decadal Survey. The scope of the NAS Decadal Survey is too extensive for the ISS to meet the requirements of all research experiments in the Decadal Survey. NASA will, therefore, also balance its use of non-ISS platforms, including potential future commercial capability, to conduct Decadal Survey research.

3. If a transition from the ISS to use of a commercial platform or module occurs, will NASA require safety standards for a commercial platform, especially if the U.S. Government is contributing to the development of the platform and plans to have NASA astronauts go there?

Answer: Consistent with the ISS Transition Principles, NASA will maintain leadership and governing responsibilities as outlined in the ISS Partnership agreements, and continue to maintain the essential elements of human spaceflight such as astronaut safety and the high-risk exploration systems.

a. Would a commercial platform need to meet NASA's human-rating requirements?

Answer: A future commercial platform would be required to meet NASA's human rating requirements if NASA astronauts are to conduct activities aboard the platform.

4. The Administration is proposing to end all direct federal support to the ISS in 2025. What other forms of support would be continued under the Administration's proposal?

Answer: NASA's vision for LEO is a sustained U.S. commercial LEO human space flight marketplace where NASA is one of many customers. The vision includes a variety of potential options, whether using the ISS, commercial modules, or free-flying structures, together with transportation capabilities for crew and cargo, that enable a range of diverse activities in LEO. NASA will share the cost of a LEO platform with other commercial, Government, and international users. This allows NASA to distribute its resources toward missions beyond LEO, while still having the ability to utilize LEO for its ongoing needs. It is essential to note that ending direct federal support does not equate with ending Government funding of LEO activities, which are essential to maintain long-term U.S. pre-eminence in human spaceflight and LEO.

NASA will continue to have a need in LEO for regular crewed operations, exploration-related health and performance research, long-term technology development and demonstrations, and Earth, space and life and physical sciences research. Access to an orbital platform on which to conduct these activities will be key as NASA and its commercial and international partners prepare for crewed missions to the Moon and beyond.

5. During the question and answer session of the hearing, you said that "*There would be some potential damage if we relied on another entity for operations in low-Earth orbit.*" Could you please expand on the nature of the potential damage?

   Answer: The Chairman asked whether the U.S. would be ceding leadership if we did not maintain a LEO presence, given China's plans for a LEO station in 2022. America's pre-eminence in space will continue. It is important for U.S. leadership in space that the U.S. maintain diverse capabilities to enable a variety of activities in the space environment, including operations in LEO that enable NASA's exploration goals and benefits to humanity.

6. In response to a question during the hearing, you stated, "*Probably within 1 year we'll have two providers being able to carry crew to low-Earth orbit. As we think to the future beyond low-Earth orbit, we think transportation is clearly a key driver, so we want to make sure there's not unique systems, that the systems used for low-Earth orbit can be basically the same systems used for deep space.*" Could you elaborate on this point?

   Answer: NASA will partner with commercial entities in its cislunar activities, and some of the systems used may overlap with some used in LEO. For example, NASA will use the heavy-lift Space Launch System (SLS) to support key cislunar missions (e.g., launch the Orion crew vehicle and Gateway's Habitation Elements) as well as purchasing commercial launch services for cargo transportation. NASA also has plans for the Gateway Power and Propulsion Element to be launched on an industry-partner-provided commercial launch vehicle and anticipates commercial vehicles will support near-term lunar lander opportunities.

   NASA is working with international spaceflight partners and industry to create spaceflight interoperability design standards. We believe these standards will improve interoperability capability in future human spaceflight systems between spaceflight providers, increasing options between providers, improving spaceflight competitiveness and lowering overall costs.

a. Do you envision using Atlas 5 and Starliner or Falcon 9 Block 5 and Crew Dragon launch capabilities for crew transportation to the Gateway and beyond? If so, could you please explain what, if any, modifications would be needed for crew transportation beyond low-Earth orbit?

Answer: NASA's plans are to use the SLS and Orion crew vehicle to transport its astronauts to the Gateway, and keeping the option open for additional crew capabilities to support Gateway operations in the future should those capabilities prove viable. In implementing Space Policy Directive-1, NASA also plans to pursue human and robotic exploration beyond LEO using commercial partnerships. The interoperability standards in development also include the systems necessary for common docking systems. While these standards allow for crewed visits by vehicles other than Orion, the Agency defers to the specific commercial providers mentioned for details about their capabilities to send crews or payloads beyond LEO.

Responses by Dr. Bhavya Lal

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"America's Human Presence in Low-Earth Orbit"

Dr. Bhavya Lal, Research Staff Member, IDA Science and Technology Policy Institute

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

1. Having worked on IDA's STPI market analysis for a private space station, what are your thoughts on any additional data and information related to prices/costs, requirements, nongovernment demand, and commercial readiness NASA and Congress will need in order to determine the next steps for moving beyond the ISS and toward the use of a potential commercial platform?

   Answer: With regard to the revenue estimates, we believe that NASA has a window over the next several years to more fully open up the ISS to support activities of private providers of services in space. Potential private providers have an opportunity to find out whether activities such as manufacturing exotic fiber optic cables or hosting private astronauts in space are likely to be commercially viable. At this point in time, other than the case mentioned below, market *tests* (drawing on support from the ISS) rather than market *studies* would be the best way to determine whether the proposed activities can be profitable.

   There is an area that might be worth a more in-depth forecasting study: satellite assembly and manufacturing in space. In particular, it would be of value to develop better estimates regarding: (1) whether there is cost saving or other value to in-space manufacture/assembly versus launching complete systems; (2) the extent to which assembly/manufacturing in space requires humans in the loop, especially in the near-term; and (3) whether a satellite assembly and manufacturing platform is compatible with a space station in low-Earth orbit performing other functions, or if it would be better suited for a robotic platform in geosynchronous orbit.

   On the cost side, further studies in the following areas may be useful: (1) A more detailed breakdown of ISS expenses, and an examination of specific ways the private sector could reduce those costs; (2) A more detailed assessment of potential operations costs that a new private station would incur; and (3) Estimates of timelines associated with the privatization of ISS or launch of a commercial entity's own station.

2. The ISS Transition Plan lays out steps that NASA and the Administration plan to take as part of an ISS transition strategy. Those steps include:

   - soliciting inputs from private industry on their interest in carrying out ISS operations and on the development and operations of private on-obit modules and/or platforms;
   - consulting with international partners and stakeholders on the future of the ISS after 2024; and
   - developing a commercial use policy for ISS resources such as crew time and up and down mass.

   What further steps, if any, should NASA be considering and why?

   Answer: In order to ensure a successful ISS transition, in addition to the activities listed above, NASA should scale up its effort to help commercial entities prove out concepts and technologies on the ISS. This would help assess whether specific commercial activities are economically viable on the ISS, and ensure a smooth transition to a privatized or commercial space station.

3. A commercial platform might focus on manufacturing in space, e.g., fiber optic cable manufacturing, in order to make a profit. The environment on such a platform might not be compatible with the requirements of NASA's fundamental research community. Is there a viable business case for a commercial platform solely dedicated to fundamental research or would it need to be fully funded by the federal government to be viable?

   Answer: Our study found that a human-tended, private sector space station relying solely on hosting experiments focused on fundamental (i.e., basic and applied) research is unlikely to be commercially viable. However, the environment for manufacturing products in space is likely compatible with the requirements of NASA's fundamental research community such that they can cooperatively exist on the same station, especially if that station is robotic. If there is fundamental research that requires a human presence on the station, the task is more complicated, but nonetheless doable.

   In other words, as with fundamental research on Earth, the business case for a commercial platform solely dedicated to fundamental research is weak. However, many businesses are eager to engage in such research if it were financed by the government. Given that fundamental research is critical for our country's leadership in space, it would be worthwhile for the government to continue to support fundamental research on a privately owned and operated space station.

Responses by Dr. Elizabeth R. Cantwell

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"America's Human Presence in Low-Earth Orbit"

Dr. Elizabeth R. Cantwell, Chief Executive Officer, Arizona State University Research Enterprise (ASURE), Arizona State University

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

1. During the question and answer session of the hearing, you said, "*We have, on the committees that I've served, queried mostly new space companies over the last three or four years, seeing this transition coming. And what we find—I will just say that what we find is a unique willingness to work with the science community to find ways as we progress and innovate these new business models to accommodate science. That has certainly not come to any clear conclusions at this point, but we do find that particularly American companies are more interested in supporting American science.*"

   a. Could you clarify what you mean by new space companies willingness to "accommodate" and "support[ing]" science?

      Answer: We have found that companies trying to create new commercial opportunities in LEO are interested in talking about how to accommodate science on their platforms. Discussions have largely focused on filling unused volume with autonomously operating science experiments and/or developing small-scale science within the context of student programs to encourage and develop workforce pipelines. We're encouraged by the implicit recognition that investment in basic science fuels America's economic success. That said, funding models for accommodating larger-scale, continuous and/or crewtime impacting science have not yet seen a lot of discussion.

   b. Will the science community require financial support from the Federal Government if a platform that is owned and operated by the private sector is used by the science community?

      Answer: Generally, yes. It's important to understand exactly what the overall costs of research on ISS is, including full costs of pre-and post-processing, launch and on-orbit operations, and hardware development. To date, many of these costs have been rolled up under other accounts than research accounts.

      Generally in the US, discovery and new knowledge focused research has been the purview of Federal Agencies. Companies look for either IP of interest or research evidence that can solve a specific problem before they are willing to invest.

Congress should be very clear about the many elements of good research programs – if there is a translational component, companies MIGHT pay part of that, but only if they understand what is being funded and why. They are less likely to pay for discovery components and other early investments, which returns on investment might not be recognized for years, if at all. Therefore, companies should be engaged in the development of a business model for science in LEO that allows them to clearly define where and how they would be able and willing to be funding partners. The rest of a robust science portfolio will need financial support from the Federal government.

2. In your prepared statement, you suggest that Congress work with NASA to "*strengthen the relationship between university research and the growing LEO commercial sector through real, meaningful incentives*." Could you provide examples of some incentives that you think should be considered, and why?

   Answer: Create science set-aside requirements in NASA LEO commercial contracts that require a percentage of the contractual value be used to fund science. There is precedence for this at the European Space Agency. Why? Because it creates stronger ties with basic research programs often housed in academic settings and creates new avenues to fund graduate students, co-ops and internships. There are many ways to manage this: examples can be found in the US and elsewhere. The paradigm change is shifting more of the responsibility of implementation to corporate partners, ensuring that they become more and more invested in science and its value. Ultimately, everyone wins and US technological prowess is sustained.

   Develop a LEO workforce pipeline working group with the commercial sector that focuses in part on the workforce needed for the knowledge economy that will be part of future of a US presence in LEO. Why? This is a way to guarantee that we are all thinking about how to fund the next generation.

3. Your prepared statement states "*the breadth of science and technology objectives is critical to responding to exploration needs and scientific opportunities*." You further state that, "*NASA will need to communicate a clear demand signal for a flexible platform. Otherwise, they may find themselves unable to pursue critical lines of emerging research*." Could you expand on the importance of a flexible platform? How could it be defined as part of the transition strategy?

   Answer: The US, across both NASA and the science communities, spent many years developing and implementing science requirements for the ISS. This kind of science requirements process should be considered for other options such as multiple small platforms. As opportunities in LEO expand, the processes will be different: ISS is one platform, and we envision many different types of platforms all residing in LEO. Nevertheless, there are common parameters that must be considered. Examples include thermal and vibration requirements, duration, repeats needed, human tending requirements and sample return requirements. As mentioned previously, the ability to modify experimental platforms based on results as they go along is important in long-term science programs. Options may be very important that were not envisioned at the outset (for example, an experiment that runs at only one temp, but it is discovered that multiple temps are needed to get successful results). Only recently the ISS has acquired some ability to iterate design of hardware in the space environment, and this adds a new and exciting dimension to technology development.

a. Would multiple small platforms provide such flexibility?

   Answer: See above.

b. How should NASA and ISS stakeholders define and communicate the needs for "the breadth of science and technology objectives" to which you refer?

   Answer: The complexity here is that this is now a needs analysis across multiple potential platforms – with ISS it was only one platform. It would be prudent to thus start with a set of needs, established by a process that could, for example be embodied in the upcoming space life and physical sciences Decadal or other planned science requirement development activities. Alternatives could include working groups established by NASA, establishment of a sub-group of the NAC or commissioning of a National Academies study.

c. Would a commercial platform focused on manufacturing provide an environment compatible with the requirements for scientific research or would separate platforms be needed?

   Answer: Commercial platforms could be complementary, but understanding the specifics of such planned environments would be necessary before credible answers to this question can be determined.

4. In your prepared statement, you note that "*NASA must seek to better understand and better mitigate the long-term effects [of] microgravity in both biological and physical systems involved in extended missions in deep space, and do so on the time scale measured in years.*" Other than Scott Kelly's one-year mission, have such long duration research projects occurred? If not, why not? To what extent could an alternative, nongovernmental orbiting platform or platforms accommodate long duration research?

   Answer: I stated that 1-3 years is needed for LEO-based research to be relevant for true long-duration planetary exploration. I am aware of no long-duration fractional gravity experiments that have been performed on this time scale, and it is pointed out in the recent Mid-Decadal Report on Life & Physical Sciences in Space that critical areas such as biomedical research and flame research will require such studies. In addition, sufficient (i.e. 3 years) studies have NOT been conducted at zero-gravity either. Theoretically, non-government platforms could help, especially if they have continuous multi-year access. But that depends heavily on their ultimate configurations, and an adequate profit structure for companies to incentivize participation for these periods of time.

5. Your prepared statement notes that "*Congress should encourage costing and pricing paradigms for NASA-supported S&T that fully enable a range of platforms, analogs, and ground based facilities.*" Could you expand on this point? What types of paradigms should Congress consider?

   Answer: The basic idea is that no commercial entity will assume the full cost of conducting research, and will ordinarily fairly require coverage of those full costs. Currently the key missing piece is full cost accounting for research on ISS. NASA-funded research on commercial platforms in LEO will inevitably be fully costed. Understanding these full costs will enable a better look at both analog and ground-based facility research and help NASA understand what can be done at the best cost and where. The same concern was voiced in the ISS Transition Report delivered by NASA to Congress (30-Mar-2018). Additionally, on commercial platforms, the issues of IP will become more and more complex – I would personally recommend that we begin to address this as a joint NASA/science community activity as soon as possible.

6. The ISS Transition Plan lays out steps that NASA and the Administration plan to take as part of an ISS transition strategy. Those steps include:

   a. soliciting inputs from private industry on their interest in carrying out ISS operations and on the development and operations of private on-obit modules and/or platforms;
      Input: I also recommend input from academia as these steps are planned and executed. This is where the majority of discovery research and innovation in the US is happening today.
   b. consulting with international partners and stakeholders on the future of the ISS after 2024; and
   c. developing a commercial use policy for ISS resources such as crew time and up and down mass.

   What further steps, if any, should NASA be considering and why?

   Answer: NASA should consider a developing a clearly articulated science access and management policy for NASA-funded research after 2024. It's an important tool to assure that NASA's exploration goals can and will be met with greater reliance on the commercial sector. Science management means managing the actual conduct of the science all through its entire lifecycle. It is also important to have some version of a science continuity plan, describing how the current science efforts will be transitioned from ISS to the next generation of platforms. Examples for this kind of transition planning requirement can be found in the NSF Engineering Research Centers (ERCs) and the DoD Multi University Research Initiatives (MURI) programs. (https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5502) https://www.onr.navy.mil/Science-Technology/Directorates/office-research-discovery-invention/Sponsored-Research/University-Research-Initiatives/MURI.aspx)

Appendix II

ADDITIONAL MATERIAL FOR THE RECORD

LETTERS SUBMITTED BY COMMITTEE CHAIRMAN
LAMAR S. SMITH

American Society for Gravitational and Space Research

Biology and Physical Sciences Bridging Earth and Space

www.asgsr.org

May 11, 2018

Chairman Lamar Smith
House Science Committee
2321 Rayburn House Office Building
Washington, DC 20515

Ranking Member Eddie Bernice Johnson
House Science Committee
394 Ford House Office Building
Washington, DC 20515

Dear Chairman Smith and Ranking Member Bernice Johnson:

The American Society for Gravitational and Space Research (ASGSR), founded in 1984, brings together diverse group of scientists, engineers, and students from academia, government and industry to promote microgravity research, education, training and development in the areas of space biology and physical sciences. The knowledge gained from this research leads to a better understanding of the effects of gravity on living and physical systems on Earth, in space, and enables human space exploration.

The American Society for Gravitational and Space Research submits this testimony for the record to provide insight of needs in the microgravity science community for research on Earth, in low-Earth-orbit and beyond.

In general, the spirit of the ISS Transition Report is sound – and we particularly appreciate many aspects, including the continued NASA or Other Government Agencies' (OGA) stewardship of science support, and the recognition that the precepts of the National Academy of Science (NAS) Decadal Survey are important. The concept of the National Laboratory as a model is also sound, particularly when placing the focus on traditional National Lab models, such as Brookhaven, Oak Ridge, etc., which are typically run by a business consortium, while PI research is supported predominantly through government grants. The National Lab model works well, and there are many examples where the intersection of commercial, academic and basic government research all come together in this model.

Yet the ISS Transition Report is a strategy without an actual plan in place to bring the strategy to life and it does not make a clear commitment to making full use of the ISS. ASGSR strongly believes that a commercial commitment, or even defined interest that could be included in the report, would go a very long way. As it stands, the strategy is not grounded in a confident business model.

The bigger question is how do we as a nation see ourselves in the world, and what are our general priorities? If our national priority is to maintain our preeminence in space research, and all the attending spin-offs of technological development and preeminence (communications, security, material science, fuel and energy, etc.), then this would be a tragic time in our history to pull back. In the past few years, we as a nation have seen a tremendous upswing in our ability to develop new spacecraft, new technologies, and new public enthusiasm in space research; the slope of those advancements being largely driven by commercial endeavors. It would seem that a revitalized government investment in space research at this time in our history would serve to synergistically move forward all aspects of space research, space exploration, and space utilization, to create an unparalleled environment of innovation and discovery. We have an exquisitely trained young workforce now, poised and ready to excel. If we lose this momentum – a momentum currently being exploited by the very commercial partners NASA is hoping to entice to take over ISS management – we run the risk of creating a serious gap in national capability in technological fields in many arenas, not just aerospace.

Fully utilizing the ISS as a science platform is a challenging goal. The ISS's relevance to basic research in biology (from plants to human health) and physical sciences (breakthroughs in materials, combustion, fluidics, etc.) not only supports our collective exploration goals for deep space, but reveals fundamental understanding of the basic workings of life and physical properties that have heretofore been unobtainable. These results feed both our fundamental knowledge but also have direct application critical terrestrial issues like energy efficiency, food production and disease virulence. This renaissance in research evokes a "proud to be human" feeling in the research community, but also creates a sense of urgency to maximize utilization of the ISS platform while it is still available. This point again ties back to the issue of capturing and maximizing the return on the current technological momentum in the field.

Using microgravity platforms in LEO, such as the International Space Station National Laboratory, and advanced exploration systems such as the Lunar Gateway, can leverage our national ability to surmount a wide range of biomedical, radiation, physical science, and engineering-related challenges. Strategic, productive and uninterrupted commitments to research by the U.S. government is critical to exploiting the space environment for advancing U.S. science and innovation agendas.

ASGSR's policy statement found at www.asgsr.org contains three recommendations. I want to focus on Recommendation #3:

RECOMMENDATION #3 Accelerate research funding levels with federal agencies, including NASA, that are utilizing the ISS for research. Acceleration of federal research funding or increase in seed grant funding will propagate into the U.S. ecosystem of scientific breakthroughs and innovation, and creating more jobs in STEM fields. As U.S. crew time availability increases on the International Space Station (ISS) with the addition of another crew member, and the upcoming increase of vehicles carrying crew and cargo to the ISS, the capacity to do more research is available; however, the ISS research budget remains stagnant and does not ramp up to take advantage of the increased capabilities. The more the U.S can stimulate demand in LEO, using federal grants and other initiatives, the more likely there will be successes in innovation and discovery that benefit the nation providing value back to the nation for the ISS investment. The outcomes from space life and physical sciences research on the ISS are essential to enable execution of space exploration missions and help facilitate research pathways that have high value applications on Earth.

In summary gravitational research is a continuum of efforts that extends from laboratories and analog environments on the ground, through other low-gravity platforms such as parabolic aircraft and suborbital rockets. If we are to explore, if we are to accelerate innovation and science in low earth orbit, the research investment needs to be commensurate with the vehicle and platform investments.

Thank you for your commitment and recognition of the need for microgravity research as we proceed in this journey together.

Sincerely,

Gale J. Allen, Ph.D
Executive Director

Anna-Lisa Paul, Ph.D.
President

About the Organization

The American Society for Gravitational and Space Research (ASGSR), founded in 1984, provides a forum to foster research, education and professional development in the multidisciplinary fields of gravitational research. ASGSR brings together a diverse group of scientists, engineers and students from academia, government and industry to promote research, education, training and development in the areas of Space Life and Physical Sciences research. The knowledge gained leads to a better understanding of the effects of gravity on living and physical systems on Earth and enables human space exploration. www.asgsr.org

May 16, 2018

Representative Lamar Smith, Chairman
Representative Eddie Bernie Johnson, Ranking Member
Committee on Space, Science and Technology
United States House of Representatives
2321 Rayburn House Office Building
Washington, D.C. 20515

Dear Chairman Smith and Ranking Member Johnson:

Thank you and your staff for inviting me to submit comments regarding the complex issues and considerations facing the Congress and our nation as we consider the future of America's Human Presence in Low Earth Orbit.

Let me begin by saying that the comments, observations and recommendations that follow are mine alone. They are not intended to represent a consensus approach from any organization I have been or am currently associated with. There are several such organizations. I have been honored and fortunate to engage with the ISS Program in my current role, as President & CEO of the Coalition for Deep Space Exploration, which has within its diverse membership some companies deeply engaged with the International Space Station (ISS) and others preparing to build and launch commercial platforms into low Earth orbit (LEO); as a former member of the Human Spaceflight Committee, and now a member of the Space Studies Board, of the National Academies of Sciences, Engineering and Medicine; as a Senior Policy Advisor to the Center for the Advancement of Sciences in Space (CASIS); as an advisor to NASA and a member of its LEO Commercialization Working Group; and - 20 years ago - as a manager of the Flight Operations group for the ISS Program at The Boeing Company, where along with thousands of others I helped build this incomparable vehicle that is at the heart of American leadership in space.

Perspectives on the ISS and America's Human Presence in Low Earth Orbit are diverse within and across all of these organizations. But there are two things upon which I believe all agree. First, the United States must lead in space. Second, in order to do so, an ongoing, uninterrupted human presence in space must be an unchallenged fact of American life.

Since November of 2000 this nation and the world have benefited from exactly that circumstance. U.S. astronauts have lived and worked onboard the ISS each and every day. In other words, there is already an ongoing American human presence in LEO, and we must remain there. There can be no "gap" in human spaceflight. Therefore a weak or interrupted transition between operations in low Earth orbit and operations in deep space that enables such a gap cannot be allowed. Further, there is no need to play human presence in LEO and in deep space off against each other. To do so is a false trade that is not in the best interests of the United States. Our success in deep space is intrinsically linked to our leadership in LEO.

The United States through NASA is now building the next generation super-heavy launch vehicle – the Space Launch System – and the next generation crew vehicle – Orion. Both are destined to help open the solar system and take human beings deeper into space than we have ever been before, on long-duration missions. At present the ISS is the only laboratory enabling research into the effects of space on the human body, on performance, and on cognitive and emotional health. It is also the only facility capable of providing thorough testing and run out of systems needed to enable human exploration of deep space still close to the Earth, in LEO. Finally, the ISS is currently the only means by which American astronauts gain experience in space in a regular cadence. This is also important to maintain operational proficiency on the ground. All of these capabilities are accessible in just a few hours after launch. They will continue to be needed even as NASA moves toward assembly of a lunar Gateway, and accelerates both robotic and human activity in the vicinity of the moon, looking forward to Mars.

At present, the agency's plans anticipate the evolution of both supply and demand in LEO sufficient to attract investors, developers, suppliers, and those looking to purchase goods, services, or capabilities in low Earth orbit, giving rise to a "commercial market" robust enough to support one or more new orbital facilities to follow the ISS. Such business entities could eventually offload some of NASA's costs by underwriting transportation for example, or by paying for it outright. Those costs would then be amortized across the marketplace writ large, freeing up funds that NASA could turn toward human exploration and development of deep space.

On Earth, economic development plans take time and are somewhat unpredictable, although they can be tracked via milestones and achievement (or lack thereof). An economic development plan including both Earth and low Earth orbit in its sphere, however, has never been tried before, making such tracking difficult and prediction impossible. The <u>real</u> problem is LEO is one of demand. Any commercial provider interested in attracting investors must be able to assemble a business case that involves more than just the government as a customer in order for the government to be out of the critical path and to avoid a long-term situation in which the government ends up in effect paying for another orbital platform. In addition to serving as a customer, however, another role government can certainly play is to ensure that it "gets the rules right" in low Earth orbit by removing barriers and potentially providing incentives to encourage both supply and demand.[1] It should be noted, however, that there are no guarantees with this approach.

---

[1] Dittmar, M. L. (2014). "Getting the rules right: LEO as an economic development region." The Space Review, September 15. http://www.thespacereview.com/article/2600/1

International partners are also stakeholders in the ISS. They are deeply vested politically, financially, and culturally. Regardless of whether they wish to continue the ISS after 2024, all of the participating space agencies have restated their commitment to the ISS partnership as the framework that will carry us into deep space. The impacts of U.S. leadership in low Earth orbit upon our international leadership on a broader stage can hardly be overstated, and it is through the ISS that the U.S. continues to lead. Continued engagement with international partners through the ISS is important until such time as a strong international program is established beyond LEO.

This is especially critical now that the Chinese are preparing to launch Tiangong-2. The mission cadence for deep space and the funding profiles under discussion now in the U.S. may not be sufficient to attract and maintain cooperation with other nations and to maintain the leadership role we have enjoyed to date. The Chinese are reaching out, teaming with other agencies and with institutions across the globe, offering opportunities for joint missions and for joint research projects in low Earth orbit. These offerings may become increasingly attractive to researchers with long-term research programs and to other nations who are concerned about the uncertainties regarding the fate of the ISS and the timeline for development of commercial platforms in LEO.

All of these points lead to some specific observations and recommendations, some of which I made in my testimony before the Space subcommittee last year, and to which I would direct your attention if more information is desired.[2]

1. There must be no gap in American human spaceflight. Put more positively, human spaceflight must continue uninterrupted and at a cadence that ensures operational readiness for both astronauts and ground crews. This means continuing to transport humans from the Earth to LEO for many years to come while at the same time accelerating our plans for deep space human exploration.

2. The continued use of the ISS benefits NASA's deep space exploration program. The use of the ISS in low Earth orbit will be the most cost-effective way to ensure ongoing research both for Earth benefit and deep space exploration for the next several years. A transition to commercial platforms, when it comes, must also enable this research.

3. The international partnership at the heart of the ISS is critical for deep space exploration and the process of extending human presence into the solar system. International cooperation is achieved over decades and should be maintained through the ISS program while at the same time developing new opportunities in deep space.

---

[2] Statement of Mary Lynne Dittmar before the Subcommittee on Space, House of Representatives Space, Science and Technology Committee, March 22, 2017.
https://science.house.gov/sites/republicans.science.house.gov/files/documents/HHRG-115-SY16-WState-MDittmar-20170322.pdf

4. The establishment of the ISS National Lab aboard the U.S. segment provides a means for private interests to pursue business interests. As I pointed out last year, in order to spur demand it may be necessary to close the gap between public investment (NASA and the Center for the Advancement of Science in Space (CASIS)), private sector gain, and enough revenues to incentivize private investors to fund orbital facilities available for both public and private use. This would likely require investment or incentives on the demand side, to speed up diversification of activity in LEO and target promising development efforts. There are several mechanisms available that could be tried – and many of them, it should be noted, are outside NASA's authority.[3] However, the government should stay firmly out of the business of "picking winners"; rather it should help companies who are already raising their own capital rather than relying solely on government funding. NASA is not a venture capital firm nor should it attempt to fill the revenue gap itself unless it has specific needs for the offering, as a customer.

5. Economic development of LEO offers the opportunity to reduce government costs and transfer some available funds to deep space exploration and development. That said, timelines are uncertain, and it is likely that the government will remain on the hook at least for transportation costs for some time to come. However, not to try is to fail, and every opportunity to spur utilization of both ISS and LEO should be taken. This includes making available, as soon as possible, the berthing port on the ISS that NASA has been considering for a commercial module in order to enable at least one test case for generating revenues, attracting investors, and demonstrating proficient operations in low Earth orbit by a non-government entity.

6. The $150M called for in the President's Budget Request, to the extent it is supported by Congress, should be considered in light of the need to build demand as described in #4 and #5 above. Demand is currently the bottleneck for development of LEO. Just paying for more supply side capabilities may increase the probability that no company will succeed. This applies whether the platform for utilization is the ISS or a new commercial orbital platform.

7. Under no circumstances should the U.S. government cede human presence in LEO to foreign powers. In LEO and in deep space, American leadership is paramount.

Thank you again for this opportunity to submit comments to the Committee.

Best regards,

Mary Lynne Dittmar, Ph.D.

---

[3] Dittmar, 2014, op cit

AXIOM SPACE

17155 Feathercraft Lane
Webster, Texas 77598
tel 281.823.9717

May 15, 2018

Representative Lamar Smith, Chairman
Representative Eddie Bernice Johnson, Ranking Member
Committee on Science, Space and Technology
United States House of Representatives
2321 Rayburn House Office Building
Washington, DC 20515

Dear Chairman Smith and Ranking Member Johnson,

From 2005 to 2015, as NASA's International Space Station (ISS) program manager, I oversaw the development, assembly, operation and utilization of the International Space Station, both for the United States government and that of the other 14 nations invested in the program. I retired after 27 years of government service, and later co-founded Axiom Space, whose goal is to build, launch and operate the world's first commercial space station. It is with this background that I would like to submit for your consideration my thoughts on the future of this incomparable platform in the context of the Hearing on America's Presence in Low-Earth Orbit

Mind the gap. As NASA begins to shift its human spaceflight focus – and, by necessary consequence, its budget – from low Earth orbit (LEO) to exploration of cis-lunar space and beyond, one concept must remain inviolable: In order to preserve our leadership in space, the United States must not relinquish uninterrupted access to LEO for its astronauts. Needless to say, this includes both a way to get there, and an orbiting platform to continue the important activities underway today aboard the ISS.

Human deep space exploration will require the continuation of the types of tasks that are either already underway or planned for execution in the near future aboard the ISS. One is continued research into understanding the responses of the human body to the space environment. NASA's Human Research Program has been very successful in retiring many risks toward a notional Mars mission, but one set of investigations that is not scheduled to be complete before even the most optimistic retirement of ISS (FY2030) is on the effects of space radiation exposure.[1] Further, as uninterrupted crew time on orbit increases, it is likely new challenges in human health will arise that must be understood and mitigated. Secondly, microgravity can negatively affect machines as well as man; I have witnessed the unexpected failure on-orbit of many systems that were thoroughly tested on the ground. Some broke down in the first few hours of operation; others after months of successful run time. With these systems in LEO, while neither simple nor inexpensive, the logistics involved with repairing them were relatively straightforward. In a distant lunar retrograde orbit – or, worse, on the way to Mars – such logistics would be orders of magnitude more complex if not catastrophic. For this reason, it is imperative that critical hardware be thoroughly tested in LEO before such systems are deployed to deep space, and a platform on which to do so is crucial. Finally, current plans for NASA's Lunar Orbiter Platform-Gateway reflect no more than annual crewed missions of 30-day duration with astronauts from several participating countries. This cadence will

[1] NASA Advisory Council Human Operations and Exploration Committee, March 2018, ISS Status and Transition, p. 13

AXIOM SPACE
17155 Feathercroft Lane
Webster, Texas 77598
tel. 281.823.9717

severely strain NASA's ability to maintain an experienced and proficient astronaut corps. A readily accessible LEO destination will be a vital proving ground where astronauts can gain valuable spaceflight experience in preparation for more challenging deep space missions.

As important as the considerations of human research, critical systems hardware testing and astronaut proficiency are, the principal argument for the U.S. to maintain uninterrupted access to and a destination in LEO is intangible – to safeguard our position as the world's preeminent spacefaring nation. We are clearly in that position today, thanks to our leadership of the ISS partnership. But with Europe having expressed its pivot toward the Moon before us, and the impending launch of China's Tiangong-2 space station, our place at the head of the class may be in jeopardy. The mission sequence planned today for human deep space exploration – which may not begin for close to a decade – may not be of sufficient frequency or duration to maintain the interest of other nations. There will always be useful work to do aboard a LEO platform that will appeal to nation states with astronauts. It is imperative that there be no gap in access between the platform of today – the ISS – and its American commercial successor.

"No gap" refers not only to having an operational successor platform in orbit when the ISS is deorbited, but ensuring that the platform is economically viable. The greatest challenge facing a company attempting to deploy a commercial space station is not technical; it isn't even financial. It's the uncertainty in the demand to help close the business case. To be clear, I'm not suggesting that NASA be an anchor tenant. In fact, the only way for NASA to eventually divert much of the $3.5B+ that it's spending today on ISS to deep space exploration is by NOT being the anchor tenant. A truly commercial platform will succeed only if it has multiple customers – both private and government. In the short term, NASA's role should be limited to making unique ISS resources available for potential commercial partners, and to stimulating demand for on-orbit services post-ISS.

Award the port. While it is certainly possible to develop and launch a free-flying commercial space station, there are numerous advantages to starting with one or more modules attached to the ISS, and then to separate them prior to the lowering of the ISS altitude in preparation for its deorbit. With modules attached to the ISS, a company can use revenue generated from their utilization to offset capital requirements and consequent investment needs. More importantly, such an arrangement would allow a commercial operator more time to establish a viable customer base, and would permit NASA to transition not only its research that is underway on ISS, along with attendant hardware, but also that of National Lab customers. There is clear benefit to both the government and to the commercial space station developer to first attach one or more modules to the ISS.

In the summer of 2016, NASA issued a Sources Sought solicitation "Advancing Economic Development in Low Earth Orbit via Commercial Use of Limited Availability, Unique International Space Station Capabilities." In it, NASA stated:

> NASA will use the results of this RFI to guide development of a possible future announcement of opportunity appropriate to the Agency's objective of fostering a self-sustaining commercial marketplace in LEO. NASA is seeking industry ideas to stimulate economic development through the use of unique ISS capabilities such as unused common

AXIOM SPACE
17155 Feathercraft Lane
Webster, Texas 77598
tel. 281.823.9717

berthing mechanism (CBM) attachment ports, non-standard attachment sites or any other capability which can be used in a way not previously envisioned.[2]

Responders were given six weeks to respond. Now, almost two years later, industry is still waiting for the "announcement of opportunity." In the meantime, in its FY2019 President's Budget, the Administration has expressed a desire to defund the ISS as early as 2025, rather than the date presumed by many of 2028. These two events combine to reduce the time available for developing a robust, commercial replacement for the ISS by up to five years. And the clock is still ticking. NASA recently indicated it would soon release a NASA Research Announcement (NRA) for the "Study for the Commercialization of Low Earth Orbit." The anticipated NRA schedule shows awardees being selected in June or July, contracts finalized in August, and study products due in December 2018.[3] If these studies will be used to inform the aforementioned announcement of opportunity to compete for the berthing port, it is reasonable to expect the awarding of the port will occur no earlier than next summer. While it is clear this recent NRA announcement will significantly delay the development of a commercial replacement for ISS, it is unclear how any study about an emerging market will change the need to help facilitate (not fund) a commercial space station provider as soon as possible. In fact the reverse is true. Once a commercial space station provider is awarded the port the investment dollars will become available and the provider can begin to make customer commitments. These commitments will be tangible indications of the types of customers that can be expected in the near term and provide a better forecast for future revenue generators.

It is difficult to imagine that an investor would commit a significant outlay – the kind necessary to build one or more space station modules – to a commercial company that doesn't have access to an ISS berthing port. The start of construction, which will take several years to complete, depends on this investment, which in turn depends on the award of an ISS port. Once the module(s) is complete, it must be launched, docked and integrated with the ISS. And, of course, all of this must occur before any customer could utilize the module. So, the award of a berthing port to a company is the first domino that must fall in a chain of events, each of which relying on the previous, that will lead to a sound decision that the nation is ready to transition its human LEO activities from the ISS to one or more commercial operators. Each day NASA delays this port award, it correspondingly postpones the moment when it can reasonably shift its ISS operations budget to that of deep space exploration.

Build demand. The FY2019 President's Budget includes $150M for LEO Commercial Development. As the head of a commercial space station company, you might reasonably expect that I'd like to receive some of that money to put toward design and building of one or more modules. I do not. To award contracts for development of hardware is to put NASA funding in the critical path for success, and threatens to hold the Agency hostage in the event the awardee would need more money to complete their design and build (which is almost certainly to be the case). Although the Commercial Orbital Transportation System agreements and follow-on Commercial Resupply Services contracts were both innovative and successful, NASA is the only customer for those services, and without its funding the companies would surely discontinue manufacture of the Dragon

[2] Federal Business Opportunities, Advancing Economic Development in Low Earth Orbit via Commercial Use of Limited Availability, Unique International Space Station Capabilities
[3] NASA Solicitation and Proposal Integrated Review and Evaluation System, Study for Commercialization of Low Earth Orbit, Industry Day Charts, p. 15

AXIOM SPACE
17155 Feathercraft Lane
Webster, Texas 77598
tel. 281.823.9717

and Cygnus spacecraft. To avoid being put in the same posture with a commercial orbital platform, NASA should give priority to companies who raise their own capital, instead of asking for government funding. These firms will be more incentivized to succeed and to grow LEO demand beyond merely the government customer; their survival will depend on it. When NASA is the only customer, there is no driver to create demand. Public-private partnerships in this case work best when the public promotes expansion of the demand, and the private spends its own capital to satisfy it.

It is important for NASA to be judicious in selecting its partners for commercial development of LEO. It should pick those that have the best chance of success, based on the technical merit of their design, the soundness of their business case, and the pedigree of their team. It should also acknowledge that demand will be, at least in the beginning, limited. Picking more partners than there is demand to satisfy will result in the failure of the market for LEO services to develop. This further highlights the imperative that NASA use whatever funding it receives for LEO commercial development to stimulate demand, and limit supply side help to the right to use unique ISS capabilities, such as a berthing port.

Don't compete with industry. Finally, one of the principal revenue streams that commercial space station companies are considering is human spaceflight for astronauts from other nations. The ISS partnership distributes flight opportunities based on each partner's contribution to the project. Outside of these allocations, NASA should not also offer flights to other nations either inside or outside the ISS partnership, as this directly competes with the offerings of commercial companies and would severely diminish the addressable market available to them. This would not only be in violation of National Space Policy,[4] it would be counterproductive to the development of a sustainable commercial market for LEO services.

Summary. We only have one shot at making the transition of the United States' human presence in LEO from the ISS to one or more U.S. commercial platforms a success. It is imperative that we achieve it without interrupting our ability to continue the research and exploration systems testing that are planned or currently underway aboard the ISS. Ensuring continued access to a LEO platform for our astronauts will maintain our position as the world's leading human spacefaring nation. To achieve this transition in a manner that allows for the resources currently being allocated to ISS to be eventually diverted toward human deep space exploration sooner rather than later, NASA must issue an opportunity for companies to compete for the ISS berthing port as soon as possible. Further, any funding made available to NASA to help develop a commercial capability in LEO should be spent on building demand. Finally, in its efforts to build demand, NASA should be mindful of not competing with industry.

I would be happy to discuss any or all of the above with you, your committee, or your staff.

Sincerely,

Michael T. Suffredini
CEO

---

[4] National Space Policy of the United States of America, June 28, 2010, p. 10